Implementing Innovative Constructivism: An Architected Approach to Enhancing STEM Education

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ABSTRACT

Constructivism in education is a well recognized approach to teaching science, but often fails to achieve its goals, especially among students who have not been inculcated with cultural norms that emphasize the importance of aggressive inquiry and the challenge of existing dogma. The primary author has developed and implemented an approach, founded in constructivist theory, which provides a carefully architected framework in which the students can learn by engaging in scientific inquiry, rather than memorizing facts in a didactic environment. The need for and benefits of the architected framework are laid out. The applicability of this approach to DoD education, ranging all the way from the DoD Education Activity up to the Staff Colleges, is discussed and justified. The authors' assert that modern warfare has driven the need for pervasive education into all ranks. The initial instantiation of the method was conducted in Biology classes in a school district in the Los Angeles basin, whose student population was extremely diverse, in both ethnicity and socio-economic status. The authors present the basic method implemented, discuss its development, adduce data on its impact on students and comment on its maintenance over time. Further, they discuss the extensibility to other sciences, to other educational levels and to DoD education. A short review of current parallel efforts to improve science education is presented, with analyses as to the compatibility of this approach with others. The issue of the potential requirement of a charismatic "hero teacher" for success of various approaches is considered. Acknowledging the move toward serious games and on-line instruction, the authors present their experience in distributed simulations and the utility of them in educational contexts. The implementation of this approach in either the serious game or on-line education environment is explored. On-going and future research is outlined and various options are analyzed.

ABOUT THE AUTHORS

Erik C. Elstad is a member of the Board of Directors at Share Science and a practicing classroom instructor of biology at the Bellflower Unified School District in the Los Angeles basin of Southern California. His research interests are in innovative ways to radically alter the way science in taught at the secondary level. His master thesis and research addressed constructivism in science education. As part of his out of the box thinking, Erik has developed a way of using conceptual building blocks to enable students to manipulate or to create their own models. To support his formal education, Erik has practical experience working for the Department of Fish and Game and a Marine Biological Consulting firm. Erik Elstad is passionate about making positive contributions to the educational community. His received a BS in Biology and a Teaching Credential from California State University, Long Beach and an MEd from Concordia University, Irvine California.

Dan M. Davis is a consultant for the Information Sciences Institute, University of Southern California, focusing on large-scale distributed DoD simulations, including being the Director of the JESPP project for a decade before he semi-retired from USC, where he now consults. Prior to that, he was the Assistant Director of the Center for Advanced Computing Research at Caltech, where he managed Synthetic Forces Express, bringing HPC to DoD simulations. Dan also served as a Director at the Maui High Performance Computing Center and as a Software Engineer at the Jet Propulsion Laboratory and Martin Marietta. He was selected as 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. He saw duty in Vietnam as a USMC Cryptologist and retired as a Commander, Cryptologic Specialty, U.S.N.R. He received B.A. and J.D. degrees from the University of Colorado in Boulder.

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INTRODUCTION

This paper addresses the potential benefits of enhancing education of defense personnel by incorporating an approach that centers more on self-discovery and less on memorization of presented facts. The most natural form of conveying important information to another is just telling them what they need to know. That, and its written forms, still constitutes the majority of educational efforts. But, even centuries ago, the emergence of more complex concepts called for deeper understanding by the students. Socrates is associated with a more thought-provoking style of education, that of asking questions and prompting the student to learn by challenging their assertions. This method is most commonly used today in law schools. In the early 20th century, a Swiss theorist and researcher, Jean Piaget, developed a new way of assessing how humans learn (Piaget, 1952) and this spawned a new approach to the education of our young people (Wadsworth, 1996). This approach goes by the name "Constructivism." This approach emphasizes student discovery and exposition of their analysis, with one group (Bybee et al., 2006) citing five steps known as the "Five E's": Engage, Explore, Explain, Elaborate and Evaluate. Engage – establish student interest in the topic to be covered; Explore – facilitate individual or small group research and observation; Explain – charge participants with deriving reason for the observations; Elaborate – challenge comprehension and expand by questioning; and Evaluate – employ self-assessment of understanding and value of knowledge (Eisenkraft, 2003). While this may take longer, this method is held by some to be more effective in fostering critical thinking, which is a dispassioned and objective analysis of reliable data in an ordered way. Needless to say, there are myriad of proponents and detractors for all systems of education (Matthews, 1993) and this paper does not purport to resolve any of those issues. There are some times when each of the various techniques may seem optimal. This paper will report on and analyze a methodological variant of the use of constructivist approach to teaching sciences using a framework to assist students in their early exposure to this method. While the didactic approach to education and training is one of the more intuitive methods of imparting information in both civilian and military contexts, its critics observe that it has some limitations that merit reexamination. One assertion is that a pure lecture approach, while efficient in many training scenarios (Joyce *et al*., 1992), tends to not be as efficient in generating deep understanding of the underlying issues and broader ramifications of the material (Guillot, 2006). It does not optimally promote critical thinking and can induce, in its least effective implementation, a parroting of the teacher's statements and a regurgitation of the assigned text without challenging the learner to justify or apply the lesson. On the other hand the constructivists' approach teaches by structuring a problem to be resolved and challenges the student to research and learn whatever is necessary to resolve the issue. Learning styles and critical thinking are better addressed by this method, as it is up to the learner to choose whatever style or meta-cognitive approach is best for their extensible mastery of the issue.

However, in practice, the constructivist approach has two distinct and observable hurdles: 1) students who have been taught didactically find it uncomfortable to leave the security of relying on lectures and, 2) being unfamiliar with having to find their own path to learning, students often get confused and disoriented, with concomitant break-downs in educational focus and loss of behavioral discipline. The objective of this paper is to disseminate the primary author's two coordinated approaches: constructivist frameworks and engaging models and scenarios, which were designed to avoid or to mitigate these negative impacts. It also appears to improve the cultivation of critical thinking and the education of those with non-verbal learning styles.

There are three tenets that will be addressed below: 1) Education is increasingly vital for all levels of DoD personnel; 2) Constructivism is an approach to education that has many benefits, instilling deep understanding and creating an impetus to apply what is learned; 3) Architectures in constructivism make the transition from didactic lecture to constructivist exploration less daunting and more productive. A subset of the architecting process is the use of computer-aided simulations and avatars, especially in the context of DoD operations. These concepts will not be presented *seriatim*, but will be recursively discussed throughout the paper.

Although somewhat orthogonal to the major theses of this paper, it is acknowledged that there are many current concepts of interest to the educators' profession that may intersect with this work. Besides constructivism, another layer has been laid on top of the educational systems of most developed countries: the design and use of tests to assess a student's ability to successfully engage in studies offered (Binet, 1916). These are commonly called "IQ Tests" or aptitude tests (Snyderman & Rothman, 1987). In the latter part of the 20th century, an American researcher, Howard Gardner, proposed that students actually have several important intellectual abilities, not all of which are captured by "IQ Tests", *e.g.* visual-spatial and kinesthetic (Gardner, 2006). This suggested to some educators (Coffield, *et al*., 2004) that some students would learn better if presented a series of images and models of the material they were to master or others might excel were they allowed to physically manipulate objects or models of the issues under study (Pashler, 2008). While this theory has been challenged by some (Waterhouse, 2006), the approach discussed here addresses some of these issues as well (Armstrong, 2009).

This paper will set out the areas where new approaches to education may be appropriate, review the theory behind one of those: constructivism, discuss some of its limitations, describe a new implementation of this approach, analyze its successes, and discuss its potential in the DoD environment. Then the paper will consider some alternative approaches to deliver this approach in the geographically dispersed and time-constrained military environment. Both defense and civilian organizations have announced goals of achieving better educational outcomes, but they have somewhat differing environments and goals. With an occasional reference to the special needs and unusual constraints facing the defense educator, the paper will focus on the orderly progression from theory to development to implementation to delivery. Where available, the authors will adduce quantified results and observations to bolster their analysis, often garnered through associated research and parallel projects. As improved education is an important goal of all of the uniformed services and of their civilian support personnel, the paper then turns its attention on how such issues are vital to DoD educators all along the range from the Department of Defense Educational Activity (DoDEA) K-12 up through the Staff Colleges. These environments along this range are identified and briefly considered.

The implementation developed by the primary author is covered in the traditional way with this introduction being followed by the theory behind the method, the way the method was implemented, both anecdotal and quantified statistical data is presented as to observed results, and the process is analyzed to better understand the impact of the work. Then the authors discuss their other work for the DoD in distributed simulations for the traditional training, evaluation and analysis functions, and in conversational avatars as a personalized mentor and tutor. These technologies could implement an interface that would be constructive in a globally dispersed and time-constrained environment. This implementation is then laid out in such a way that would pave the way for such an implementation by others.

One of the concerns raised by members of the teaching profession is the specter of its reliance on a charismatic "hero teacher." This is a term with no ostensible consensus definition, but it is not without use (Leland, 2016) and (Ayers, 2000). The term is used in this paper to describe a teacher with the following characteristics: 1) a unique ability to motivate and educate otherwise resistant students, 2) a charisma that is part and parcel of that ability, but is ostensibly difficult to emulate, and 3) perhaps, a source of false hope, which is often perceived as more disruptive than efficacious. While the use of the term is often accompanied by hyperbole and pejorative assertions, it still is a topic which may require addressing. The concern is that, if the "hero teacher" is a *sine qua non* for implementation, even attractive results may not be reproducible by other teachers.

In the implementation reported on below, the goals were set as: 1) getting a wider diversity of students interested in the field of science and 2) fostering a culture of design and creativity. This first goal had a subset of goals to achieve. The first goal of the curriculum included sub-goals of increasing the understanding of the scientific approach, instilling basic biology concepts, and developing cooperation skills. The product of this goal was to induce students to develop critical thinking skills and communication skills so they may become more independent thinkers. The second goal was more long-term and professionally oriented; it was to create a culture of design and creativity in education professionals. The authors take as a given that our country will prosper if our citizens and our warfighters become more literate in the areas of Science, Technology, Engineering and Mathematics (STEM). This is not just important for those who want to go to college, but for all who will become the stewards and defenders of this country. This set of goals highlights the dichotomy between education and training.

The intended outcomes are the abilities to generate a population of citizens and a body of service personnel who will be able to think independently and critically, and to creatively solve problems in dynamic environments. The curriculum is designed to allow students, be they adolescents or mid-career service personnel, to be engaged in real life situations and simulations, where they are able to discuss, reason, and solve problems based on evidence they have researched. The students are able to hear different points of view from students at the table, to decide which strategy is best to solve the problem and advance plans to implement that strategy. The concepts that the students not only understand, but have experienced, can be transferred into their everyday lives and professional settings. This can help make our society more perceptive about core issues and have the skill sets to resolve them.

New accessions to the military come for an adolescent population that has grown increasingly inured to the allure of science. There is a certain amount of curiosity that must be present in order for students to remain thinking and engaged in the material (Willingham, 2009). Areas of entertainment, such as video games, movies, apps and music are luring away student's attention because the game designers have researched what drives students' curiosity. With better constructed and more attractive materials, companies are spending millions on research to keep adolescents' attention. Video game designers work very hard to make video games addictive to their customers (Harrigan, et al., 2010). To some, it seems that students are learning more from video games and movies than what they learn in the classroom. This is a dangerous modification of our students' point of view on life and their philosophy of thinking because of the potentially negative impacts of movies and video games (Tompkins 2003). To combat this, teachers need to and can improve the production values in the classroom by creating better narratives that resonate with the student's life style and professional environment.

While discussing the authors' approach to implementing the constructivists' approach, the terms framework and scaffolding are central. Educational scaffolding is the process of providing students a series of steps or supports to enable their initial approach to learning a new subject or task. The framework is the author's term for establishing a structure for the critical thinking approach to constructivist problems. In order for the curriculum to be successfully received by the student, these two components need to work in tandem. This is the building of concepts and tasks that will lead to greater and more complex concepts and tasks over time. For example, for a student to create an effective model, they need to be shown in small steps how this is done. Once the teacher feels that the students have mastered this, they can move on to incorporating the model in more complex activities.

In the recent past, educators have often been the deliverers of information as a static product with only one correct answer (Schmoker & Marzano, 1999). The authors hold that this has devalued an important position for education in students' lives. They have personally observed that one of the reasons the students have lost interest in core subjects such as science, literature and math, is because their attention is diverted by non-educators who are better creators of imagery and purveyors of their "reality" than educators. Many are more interested in movies, the internet and video games than they are in school. (Gallagher, 2015) But this attraction was used to good advantage when the developers of America's Army found that their recruiting tool was a useful training utility. (Zyda, 2003) Entertainment and education are not mutually exclusive.

The construction of a narrative by a teacher may be analogous to that of an architect constructing a building. The goals of these fields are not much different; in fact, they are similar. John Lautner, the author of "The Purpose of Architecture", says that the purpose of architecture is to improve human life. In architecture, the structure must be as sensible as nature in deriving from a main idea and flowering into a beautiful entity (Lautner, 2011). Educators, in the DoD or in civilian institutions, all want, and sometimes need, to improve student's lives. The constructivist theory (Jonassen, 1992) asserts that students construct their own knowledge of the world through the meaning from their experience (Hein, 1991). By comparison, architects use the raw materials such as wood, concrete and steel to create masterful works of art. Educators can apply an equivalent framework to their lessons in the classroom. The framework is the collection and organization of the content and concepts that are designed in an organized way for the students to learn or to master. The raw materials for an educator are ideas that make up concepts and systems of concepts. Many teachers have not been trained how to teach concepts or allow their students to access these raw materials on their own (Torff & Sessions, 2005). Fortunately, there is a way to construct ideas into concepts and finally into systems of concepts through questioning. These questions and the answers to the questions become analogous to the raw materials available to architects enabling them create their works of art.

METHOD

This curriculum was constructed around a year-long narrative that seamlessly integrates all of the concepts and standards required for biology and environmental science. This relevant and consistent narrative gave the students a clear understanding of what they were to learn and what was to be expected. The same would be true for DoD topics, like strategy. The curriculum's structure was guided by "investigatable" questions that indicated exactly what the student needed to know or to do. The curriculum was accessible through proper scaffolding. The scaffolding is the delivery system specific steps that allow the students grasp the concepts for them to know and to do. By the end of the year the students needed to be able to write a claim based off of observations, justify the claim with evidence through research and defend their claim with a model. The curriculum began by teaching the students how to create a model from observations. Then, the students learned how to justify a claim with evidence through research. Finally, students were shown how to create a claim from their observations. By the end of the year, the students should have been thinking like scientists and were exposed to many scientific concepts that can be transferred to their everyday lives. This approach facilitated the student investigation of a phenomenon or a problem. Based on their service experience, the authors believe this architecting is also extensible in many contexts of defense education.

A central tenet of the authors' approach is that there are only five questions that need to be answered to create a complete idea (Porter, 2010). They are WHAT, HOW, WHY, WHEN and WHERE. Other issues such as IS, CAN, DOES and HOW MUCH, are qualifying questions that help define the idea. The qualifying questions help to identify the idea. It was found that there is structure in the five questions that go to create an idea or a collection of ideas to make up a concept. This process follows the constructivist theory of building information (Hein, 1991), but allows students to be more in control of their learning once they understand the structure of these five questions.

An idea or a concept begins by qualifying the identity of an object such as vocabulary (Academic Language). If this is not familiar to the students, then they ask a "What" question. Once it is known "What" things are in the lesson, they are to look as to "How" they are associated with one another, usually in a cause and effect relationship or a pattern.

If the students do not understand the relationship between the "What's", they are to ask a "How" question that relates to that particular "How". For example, if a student knows what DNA is, the three different types of RNA's, and that these make a protein, then they will ask, "How do DNA and RNA make proteins?". "HOWs" are a sequence of "WHATs" that are associated by a cause and effect relationship to describe a process or phenomenon.

Next, are "Why" questions. These questions are the cement that binds one idea or concept with another. The answer to a "Why" question will yield the source or cause of the process or phenomenon. The more we ask "Why?", the more one builds a network of ideas that construct a system of ideas to create a concept. For example, "Why do plants grow from sun and water?"

If a student were to pose this question, one can see that they are aware of some "How" or process and the answer to their question leads them to another process that can build on their knowledge of photosynthesis. Once they understand this concept or process, then they will be able to insert this into ecology and so on. Finally, the "WHERE" and the "WHEN" are questions that answer the position of the "What's" within the sequence of the "HOW" or "WHY". For example, "Where does evaporation occur?" or "When does insulin get made by the cell?". The construction or answering of all five questions, makes up a complete idea that is created by the student through investigation. This is not given as a set of steps that must be followed, but as an exemplar of the kind of analysis that is required for this approach.

Ideally, the design of the curriculum will follow the constructivist theories, complimented by the questioning series mentioned above. These questions are both a guide to the teachers as they organize their class plans and an aid to the students as they master their topic. As individual teachers, or groups of teachers collaborating together, the educators will be able to create a narrative by answering the five questions that complete an idea (Porter, 2010). Once the main idea or essential question is defined, then the student can separate the process into a beginning, a middle and an end. For example, one of the essential questions in this implementation was, "How do cells make proteins?", then the process could be split into the structure of DNA, transcription and translation. These processes can be turned into either a "How" or "Why" investigation question. For example, for the structure of DNA, a "How" question may be: "How are DNA molecules accessed differently in Eukaryotes and Prokaryotes?" Thus, the structure of the narrative was made clear and organized, in addition to having a set of investigative questions for the students to follow and answer. By organizing the structure of the curriculum in this manner, the teacher created a delivery scaffold and diagnosed the students' understanding of the process or phenomenon very easily. Examples of narratives that can be constructed that will increase the learning achieved would differ for each topic and for each group of DoD learners. The authors' experience in teaching is that this creative process of providing an appealing scenario or environment is central to success of this model of teaching.

At the primary author's high school, an eight foot by four foot model was built of a Zombie Apocalypse City that supported high school science goals; it was spawned, obviously, by current cultural obsession with zombies. It created an instant recall of information due to association by location of objects. This approach allowed students that have challenges with word processing to be able to keep up with students who are more capable. Defense education would require different subject matter. Because of the broad scope of the narrative, a similar approach can be used for other disciplines in science and other core classes. The model was a central component that sits in the middle of the study area for students to make observations and discover patterns that would otherwise be difficult to see or present to the student. The model is a glorified Specifically Designed Academic Instruction in English (SDAIE) strategy that gives students a concrete representation of the story (Genzuk, 2011).

Figure 1 Zombie Apocalypse City

The model of the city was built with a single narrative in mind, but may have other possibilities for students. The narrative contours national standards that can be investigated with the science and engineering practices.

For example, the narrative for biology assigned the students to a virtual group in the CDC and tasked with them investigating the Zombie Apocalypse caused by a virus through genetic engineering, involving photosynthesis/respiration, ecology, genetics and evolution. The students had to gather data from the geosphere, atmosphere, hydrosphere and the biosphere to know what resources they had to have to create a modern sustainable city. Depending on the topic at hand, the defense educator could design various threat scenarios and battlefield situations that would both challenge the Warfighters and stimulate the learning sought. The students in both contexts work in cooperative learning groups, sized to emulate their future work groups, where each person is an equally contributing part in the educational process. There should be ancillary models and experiments that compliment the narrative and facilitate the students understanding. In the DoD context, these could be related to the person's' rank.

For the narrative to be investigated effectively by the students in middle and high school, it had to be objective and concrete (Huitt and Hummel, 2003). This may hold for new military service accessions, but more and more abstract issues will come into the fore as military personnel achieve more seniority. An investigated concept model, one which either emanated from the student's understanding or was dictated by the teacher, was used to make observations and to identify patterns that allowed the student "see" the construction of their concept. This concept allowed students to engage in the narrative with a more personal point of view, in order to extract more novel solutions to everyday problems by encouraging the students' creativity. The different levels of questioning provided the structure and a path for the students to develop their ingenuity, making good use of instructional methods pioneered by earlier educators. (Keller, 1987).

Students were able to construct their understanding of the narrative through several activities and research opportunities. Additionally, videos and pictures were used to assist in their understanding of the concepts through the professionally appropriate method. To compliment the biology students' writing, they have constructed 2-D or 3-D models that answered investigation questions or solved engineering problems.

An example of such a model is seen in Figure 2 below. This is a model of photosynthesis. The water molecules (blue and red) are split by the user and placed in the light reaction (white). The hydrogen (red) causes the release of ATP and the formation of a sugar molecule (black and blue). The use of these models allows the students to construct DNA models using Lego's® blocks and may have the additional benefit of effectively engaging and instructing those whose learning capabilities are so oriented to their kinesthetic intelligence that they have a poor record of success in the didactic format. However, this is a topic for future research.

Figure 2
Photosynthesis Model

The high school students' goal was to be able to write a five paragraph essay at the end of the unit that answered a question about a phenomenon or process. The continuity of the narrative became very important and central for students, at all their levels of processing: to be able to engage, to process, and to predict what might happen. The narratives in science follow the same format of narratives in English, math, history, management, or any other subject, civilian or military.

The narrative of the curriculum followed the structure of the classic five paragraph essay. The main topic of the essay was the essential or driving question for the investigation of the phenomenon or process. This question was then broken down into three sub-questions that together, in sequence, go to answer the essential question. These were called the investigation questions. The investigation questions, as delineated above, were the individual lessons that go to answer the essential question. Depending on the level of processing and skill level, the teacher decided whether to encourage students to come up with their own investigation question or the investigation question can be broken down further into three sub-questions. These were called focus questions. Focus questions break up or "chunk" the process by answering specific questions about that process without giving the students the answer. The further chunking allowed the students to focus on parts of the process. The investigation questions were the topics for each paragraph in the essay or section in a technical report or research paper. For advanced high school students, the answer from investigation became the sentences of the paragraph. For students who required more assistance, the answers to the framework questions became the sentences of the paragraph. This type of structure lent itself to diagnosis and assessment of the students' understanding. The conclusion of the five paragraph essay was an aggregate assessment of the process or phenomenon. The body paragraphs were one of many determinative assessments that qualified the understanding of the student before they attempt any performance task.

The students were evaluated through assessment rubrics and not multiple-choice testing, i.e. assessing what the student should be able to do at the end of the unit. The language in the rubric matrix had to be written in a way to notify the student as to WHAT they needed to say, HOW they needed to say it, and WHY it should have been said in the assessments. The assessments had to include the qualifying of the Claim, Justification, and Evidence the students used to answer the set of questions.

The authors believe this is transferable to the DoD environments. While these efforts have been effective at the secondary school level, a matter of significant interest to the defense establishment (the DoDEA), a direct copy of them may be not optimal in the education of active duty personnel. The use of visual and kinesthetic aids like the Zombie Apocalypse City were designed for a specific age group, but a more suitable environment would be appropriate for the various levels of military personnel. It is left to the reader to speculate which scenarios would be the most compelling to which groups. At the highest levels of Staff Colleges, the case study method might be the most viable vehicle. Extending down into the early DoDEA elementary school demographics, perhaps a favorite TV animated character would garner and retain interest. The method advanced above requires a continuous presence and continual intervention by the instructor.

OBSERVED OUTCOMES

Considering the goals of this approach, most of the outcomes will not be observable for years, if not decades. In an attempt to ameliorate this delay without succumbing entirely to subjective anecdotal observations, a student survey was conceived, developed and administered to the students. The results follow in Table 1. This informal survey was intended to ascertain if the students were impacted in any way by the difference of the approach. A Likert-style Scale (Likert, 1932) instrument was designed and populated with twenty questions. These were implemented in a web-accessible form, using HTML and PHP. It can be accessed for all of 2017 at: http://www.hpc-educ.org/Bellflower/Profile-BioFrmwkTest.htm . Readers should feel free to take the survey; the entered data will just be discarded later. The paper's co-author attended the class and briefed the students on the purpose of the survey and solicited their participation in it. The form was tested on three operating systems, and half a dozen web browsers. There were no reported problems with the survey itself. The authors recognize the small sample size issues, but this is an unfunded study and they felt they should present the data they do have, with this *caveat*. Averaging Likert data is also problematical, but is an informal practice which the authors have observed elsewhere. (Jamieson, 2004), so the Likert arithmetic means are presented here for consideration by the reader.

Table 1 - The Initial Student Responses, N = 55

Rating	-2.0 Strongly Disagree	-1.0 Disagree	0.0 No Opinion	+1.0 Agree	+2.0 Strongly Agree	Arithmetic Mean	Fractionalized Median
Science has always been my favorite subject.	4 7.3 %	19 34.5 %	10 18.2 %	16 29.1 %	6 10.9 %	0.0	0.1
I have always gotten good grades in science.	2 3.6 %	19 34.5 %	8 14.5 %	23 41.8 %	3 5.5 %	0.1	0.3
I have always wanted a career in science.	2 3.6 %	5 9.1 %	10 18.2 %	22 40.0 %	16 29.1 %	0.8	1.0
My parents are interested in science.	1 1.8 %	6 10.9 %	24 43.6 %	14 25.5 %	10 18.2 %	0.5	0.8
I often watch TV shows or read books about science.	3 5.5 %	17 30.9 %	7 12.7 %	17 30.9 %	11 20.0 %	0.3	0.5
Biology has always been my favorite science.	4 7.3 %	8 14.5 %	12 21.8 %	15 27.3 %	16 29.1 %	0.6	0.2
Previous science classes have emphasized discovery and research.	2 3.6 %	25 45.5 %	13 23.6 %	11 20.0 %	4 7.3 %	-0.2	-0.5
This biology course is different in the way it teaches science.	22 40.0 %	20 36.4 %	5 9.1 %	3 5.5 %	5 9.1 %	-0.9	-1.2
I like discovering things on my own.	11 20.0 %	22 40.0 %	16 29.1 %	5 9.1 %	1 1.8 %	-0.7	-0.7
It helps me discover things if I have some guidance on how to do it.	6 10.9 %	21 38.2 %	16 29.1 %	6 10.9 %	6 10.9 %	-0.3	-0.5
Having the model of Riverton helps me think through the issues.	4 7.3 %	15 27.3 %	13 23.6 %	12 21.8 %	11 20.0 %	0.2	0.2
I find the fantasy setting makes the issues more interesting.	2 3.6 %	19 34.5 %	11 20.0 %	10 18.2 %	13 23.6 %	0.2	0.1
Learning how to analyze is more important than memorizing facts.	3 5.5 %	20 36.4 %	18 32.7 %	9 16.4 %	5 9.1 %	-0.1	-0.2
I use the techniques I learn here in my everyday life.	1 1.8 %	7 12.7 %	20 36.4 %	12 21.8 %	15 27.3 %	0.6	0.5
This class has made me appreciate science more.	0 0.0 %	15 27.3 %	12 21.8 %	15 27.3 %	13 23.6 %	0.5	0.5
I am now more interested in taking other science classes.	2 3.6 %	8 14.5 %	12 21.8 %	21 38.2 %	12 21.8 %	0.6	0.5
This class has encouraged me to go to college.	1 1.8 %	8 14.5 %	16 29.1 %	17 30.9 %	13 23.6 %	0.6	0.7
I would recommend that my friends took this class.	5 9.1 %	6 10.9 %	10 18.2 %	11 20.0 %	23 41.8 %	0.7	1.1
I am now more likely to pursue a science career.	2 3.6 %	5 9.1 %	10 18.2 %	15 27.3 %	23 41.8 %	0.9	1.3
Other classes should use this approach to teaching.	6 10.9 %	7 12.7 %	14 25.5 %	8 14.5 %	20 36.4 %	0.5	0.5

The questions were intended to elicit the current impressions of the students, along with some demographic data that might be germane, such as parent educational level, family size, birth order, educational goals, and interest in science. The intent was to get some impression as whether the students saw this implementation of constructivist pedagogy disruptively different from their other classes, if they were intimidated by the need to think things out on their own, if the experience heightened their interest in science, and if they would recommend this approach to others. Anecdotal evidence of improvement in learning and behavior was observed and documented, but longer linear studies are needed to quantify and verify the early observations. These were significant improvement in understanding and methodology which are important to STEM studies, as well as positive attitude changes.

Likert-like data and some analytic aids are reproduced above. These results were very affirming of the effort to meet the primary author's goals. Questions seven and eight seem to indicate that, even though the students felt previous classes did not emphasize research and analysis, the method used in this class was not seen as so different as to be disruptive. Also of note in supporting the author's goals, the last four questions reflect student increased interest in science and college and their inclination to recommend this class to others. The Pearson's correlation coefficients were more mystifying than illuminating. The highest was the correlation between those who preferred analysis to memory were the most likely to prefer this method of teaching: $r = 0.46$, and that seems understandable. However, the authors have not yet decided to make of the negative correlation of age and preferring guidance with training $r = -0.22$. Other correlations are available from one of the authors (Davis).

This curriculum has been taught for two years. There were few misconceptions and trouble spots that were observed that need to be considered when delivering the curriculum. The first misconception is the most important to consider: it is the authors' position that educators should be delivering concepts and not just information. To be clear, a concept is an abstraction or a series of abstractions derived from experience through the senses. These abstractions are then assembled together by association to form some function or process. By contrast, the information students are receiving, by and large, are packets of information that are perceived as mutually exclusive from each other. Another misconception that can arise concerns the understanding of the direction in which the information is flowing. An abstraction's direction is from experience to the neural network in the brain. The neurons that wire together, fire together. (Dugladze, *et al.*. 2012) For students to create concepts, the content must be connected or related throughout the lessons, unit, term, and course. Students direct their attention outward to confirm their understanding of experience with information they have gathered in isolated packets. The students will have varying degrees of difficulty with the mental transition. This leads to trouble spots when getting the students to put the information together in a concept. The authors have seen that the transition from discrete packets of information to developing and applying concepts may be a challenge to implement successfully for both educators and students.

DEFENSE IMPLICATIONS OF THIS WORK

As young NCO's and Commissioned Officers come to the end of their first service obligation, career choices need to be made and the authors believe that those staying in the service will increasingly need the kinds of education that can optimally be implemented using constructivist methods. The authors have presented a functioning example of how the constructivist theory can be implemented better by providing the recipients of the education with a framework to assist their transition into a constructivist environment. The need for "thinking" military leadership has long been recognized, even in some establishments as reputed for blind obedience, as the World War II Wehrmacht. (Tetlock & Gardner, 2015)

The authors assert from personal experience that these methods are extensible into the post secondary education environment. While many of the military recruits come straight from high school, pressure to pursue collegiate education is very real for active duty personnel, even mid-level NCO's. Of course, the DoD is responsible for the service academies and the Reserve Officer Training Corps at many major US universities. Further, there are a significant number of personnel on active duty who are seeking associate or bachelor's degrees at civilian universities, over which the military has some control, but very little. Still the lessons learned from this implementation of constructivism could be fostered by any number of directives or inducements to the educational entities involved. Due to operational commitments, all these educational activities will have to be designed so as to not disrupt the critical skills training, in which all service people need to continue. Following collegiate endeavors are the postgraduate opportunities offered at the various service schools and staff colleges. It is at this level that the approaches begin to include many non-didactic forms: business schools' case study method, law schools' Socratic method and masters and PhD research studies. Prescribing and designing appropriate constructivist curricula for these levels is clearly possible, but beyond the scope of this paper. At career's end, there are whole ranges of transition activities that may benefit from incorporation of constructivist techniques similar to those discussed here.

The educational topics that would be amenable to this approach are virtually ubiquitous. A professional more used to didactic education may at first find it less comfortable, but with experience, it becomes easier to see how for them to structure the subject matter to make it accessible to the students via constructivist approaches. The topics of leadership, strategy, international relations, planning, logistics, intelligence and human relations are all well suited to the approach outlined above. Even edging into the adjacent field of training, one could see the constructivist approach as being a new tool in enhancing skills in mission planning, after action assessment and reporting, management, and training implementation.

As to a second issue, the current public education system was originally designed to facilitate the transition of agricultural workers into the urban industrial environment. Enlisted personnel were expected to know how to read and write and follow orders; officers were expected to be more erudite and civilly sophisticated, but it could be said that raw courage and unflinching obedience were the hallmarks of a good military man. But times have changed and are continuing to change. Changes that used to take centuries are now occurring in years. The need to walk lock-step in formations in the face of withering fire has given way to the individual service member having to have the diplomatic skills of an ambassador and the technical mastery of an engineer. The need to learn how to think (Davis et al., 2010), and not just what to think, is greater now than ever and will likely be even more needed in the future. A benefit of the architected features of this approach is the curriculum can be easily adjusted to meet the needs of the DoD personnel that it is to serve, both in level of concept sophistication and need for structure.

A third issue is similarly amenable to the implications of this work. Education can be said to be founded on communication, wherein the educator intends to deliver his knowledge to others. The insights gained from this communication process should be applicable to other communication efforts. Military history is replete with the importance for communications to the Warfighter. Be it intelligence, operations orders, status reports, or other necessary communications, the use of constructivist techniques, like the "Five E's" or the knowledge that some perceive better visually than orally, may make a critical difference at a vital juncture. These processes, by their very nature, encourage the students to think about the way they think: meta-cognition. Critical thinking and meta-cognitive skills can be taught and have been shown to produce beneficial results. (Lehman & Nesbitt, 1990)

The last issue to be considered is the special appropriateness of the paper's frame-worked constructivism to the military environment. A lifetime of study of military history and strategic analysis has convinced the authors that more battles were unnecessarily lost due to indecisiveness than any other cause. They contend that, while constructivist approaches bring desirable critical thinking skills to the commander, the unstructured or Socratic approach may lead to a philosophizing lassitude that could lead to dilatory responses or the perception of indecision amongst subordinates that could literally be fatal on the battlefield. The frame-worked constructivist approach on the other hand, instills a regular and uniform way of rapidly assessing each new unexpected turn of events, cf. the oft cited aphorism: "No battle plan survives first contact with the enemy.". The set of issues to be resolved could easily be recast to address anticipated combat issues, but still allow the freedom to explore creative solutions. This approach may be able to withstand the pressures of combat better than other, less-structured approaches.

Two of the challenges that face the services today are decreasing funding and accelerating operations schedules. Yet the need for continuing and improving education at all career levels is assumed by the authors. To address this conundrum, the authors suggest the implementation of the basic techniques laid out above using centralized simulations, delivered on-line, and making use of emerging capabilities to replace live humans with computer generated virtual human avatars. The simulated battlefield capabilities have already shown their potential abilities to act as training devices (Lucas & Davis 1993), to operate transcontinentally (Gottschalk et al., 2010), and to engage the users effectively (ICT, 2015a). The authors assert that, at a very reasonable cost, defense contractors could modify existing battlefield simulation capabilities to emulate any period of history and set the action in any terrain conceivable. This could provide the analogs to the implementation reported above that used Legos.

This raises the daunting issues of fiscal constraints and travel issues dictated by the dispersion of personnel. The development of virtual human avatars with emerging capabilities responds to both of these issues. Already, this technique has proven effective in the treatment of PTSD sufferers (Reger, et al., 2015), and new technologies are rapidly extending the capabilities of the avatars (Nye, et al., 2017). This could easily provide a mentor around the clock.

In the authors' experience any paradigmatic change can be difficult, threatening and disruptive. Looking at the changes necessary to implement the methods outlined above and considering the stresses on the DoD today, the question may arise concerning the plausibility of successful adoption. They have experience with the instructional capabilities of large scale intercontinentally distributed simulations. They are currently engaged in several project making increasingly seamless use of computer generated avatar virtual humans (ICT, 2015b) to conduct real-time, life-like conversations at a level that many users have shown a proclivity toward "speaking" with an avatar over a live human being on-line (ICT, 2015b). These all support the notion that making education available to active duty and reserve personnel could be effectively and economically implemented for the DoD.

CONCLUSIONS

Education is increasingly vital to the defense posture of the nation. The traditional form of education, also known as the didactic method has limitations that are emphasized by the changing educational environment and the presence of many for who this teaching style is not optimal. A constructivist approach is not only possible, but evidence is mountings that it is effective at addressing some of the issues related above. Some examples from the past have depended on the gifts of unique individual instructors, Jaime Escalante being a paradigm example. The authors are convinced that this method is easily transferable to other journeymen teachers. It does not appear to be dependent on a charismatic "hero teacher." Indeed, instead it seems to be not only transferable to others, it is extensible to non-educational settings. Newly emerging computer educational tools such as conversational avatars extend the hope of effective and economical implementations. Many other techniques such as serious games are also useful in addressing the issues laid out above, and a significant research effort would be advisable in determining which exhibits the best cost/benefit ratio and which has the greatest potential of being able to be staffed at current levels of DoD personnel limits.

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