

# Cognitive load theory vs. constructivist approaches: which best leads to efficient, deep learning?

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## Abstract

Computer-assisted learning, in the form of simulation-based training, is heavily focused upon by the military. Because computer-based learning offers highly portable, reusable, and cost-efficient training options, the military has dedicated significant resources to the investigation of instructional strategies that improve learning efficiency within this environment. In order to identify efficient instructional strategies, this paper investigates the two major learning theories that dominate the recent literature on optimizing knowledge acquisition: cognitive load theory (CLT) and constructivism. According to CLT, instructional guidance that promotes efficient learning is most beneficial. Constructivist approaches, in contrast, emphasize the importance of developing a conceptual understanding of the learning material. Supporters of these theories have debated the merits and shortcomings of both positions. However, in the absence of consensus, instructional designers lack a well-defined model for training complex skills in a rapid, efficient manner. The current study investigates the relative utility of CLT and constructivist-based approaches for teaching complex skills using a military command and control task. Findings suggest that the acquisition of procedural, declarative, and conceptual knowledge, as well as decision-making skills, did not differ as a function of the type of instruction used. However, integrated knowledge was slightly better retained by the group provided with CLT-based instruction. These results are contrary to our expectation that constructivist approaches, which focus on the development and integration of information, would yield better performance in an applied problem-based environment. Thus, while contemporary researchers continue to defend the use of constructivist strategies for teaching, our research supports earlier findings that question the utility, efficiency, and impact of these strategies in applied domains.

## Keywords

cognitive load theory, constructivism, decision-making, integrated knowledge, learning efficiency.

## Introduction

Given the ambiguous threats of modern battlefields, it is imperative that troops are trained to properly manage complex, perilous situations. These proficiencies must include not only basic level knowledge, such as proce-

dural and declarative knowledge, but also higher-level cognitive skills, such as integrated knowledge and decision-making abilities. Furthermore, military personnel must be able to apply these skills in complex, unexpected, and novel situations. In other words, it is no longer adequate for troops to merely follow strict orders and standardized procedures; they must also learn to become independent problem-solvers and decision-makers. In response, the military has begun to place an

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increasing emphasis on the development of higher-order cognitive skills. This goal, however, is restricted by practical temporal and fiscal restraints. Thus, investigation of rapid and efficient training practices that support the development of higher-order cognitive skills is warranted.

### Simulation-based training

Simulation-based training (SBT) is a form of computer-assisted learning used predominantly for its high portability and cost-effective replicability (Summers 2004). Across domains, SBT has proven more beneficial when compared with traditional classroom education (e.g. Salas & Cannon-Bowers 2003; Haque & Srinivasan 2006; Dede 2007). Moreover, recent efforts are now exploring *adaptive* SBT (e.g. Schatz *et al.* 2009), which will further enhance these instructional experiences by improving their effectiveness and efficiency. For instance, adaptive SBT systems can deliver different training experiences to different trainees, based upon their past performance and personal characteristics. However, to determine which instructional strategies would best accommodate learners in these types of computer-assisted learning environments, we must investigate the theoretical recommendations provided by the leading theories in knowledge acquisition.

### Cognitive load theory (CLT) vs. constructivism

Two major learning theories have dominated recent literature regarding optimizing knowledge acquisition: CLT and constructivism. According to CLT, instructional guidance that promotes efficient learning is most beneficial (Sweller 1988). Constructivist approaches, in contrast, emphasize the importance of deep learning – a conceptual understanding of the learning material (Hein 1991; Jonassen 1999; Taber 2006; Loyens & Gijbels 2008). These approaches highlight the importance of acquiring learning strategies, or *methods* used to aid knowledge acquisition, as opposed to acquiring mere information. Supporters of these theories have hotly debated the merits and shortcomings of both theoretical positions (Kirschner *et al.* 2006; Hmelo-Silver *et al.*, 2007; Kuhn 2007; Schmidt *et al.* 2007; Sweller *et al.* 2007). Kirschner *et al.* (2006) suggest that constructivist approaches ignore the findings of cognitive architecture literature that suggest working memory (WM) has a

finite capacity (Sweller 1988). They further argue that by doing so, constructivist strategies provide learners with information that exceeds their capacity, and thus fail to efficiently guide learners' acquisition of knowledge. In rebuttal, proponents of constructivism (Hmelo-Silver *et al.* 2007; Kuhn 2007; Schmidt *et al.* 2007) have suggested that although guidance is initially necessary, encouraging learners to become actively involved in the learning process increases their ability to effectively acquire and apply conceptual knowledge. These two, mutually exclusive theories appear to be at odds both in their theoretical approach and in their recommendations made to instructional design. However, military training needs require that a compromised solution be found so that efficient *and* deep learning can be supported.

### CLT

CLT (van Merriënboer & Sweller 2005) is based on the assumption that human cognitive architecture allows only a limited amount of information to be processed in WM at a certain point in time. Consequently, any presented information exceeding this capacity may enter WM, but will not be processed or encoded into long-term memory (LTM). Alternatively, LTM is not limited by the capacity issues that plague WM. Rather, as information enters LTM and is assimilated with existing schemas, these once disparate pieces of information are integrated with previously acquired information in order to create chunks, or large, connected ideas. As learners increase in expertise, their ability to encode, assimilate, retrieve, and apply information becomes automatic and consequently taxes WM significantly less than when the information was initially acquired. Thus, proponents of CLT state that the goal of learning is to alter LTM (Kirschner *et al.* 2006) by facilitating schema construction and automation. Consequently, they have investigated instructional practices that promote learning efficiency by managing or optimizing WM load during the acquisition process (Sweller *et al.* 1998; Paas *et al.* 2004; van Merriënboer & Ayres 2005; van Merriënboer & Sweller 2005).

Three discrete types of cognitive load have been identified (Paas *et al.* 2004; van Merriënboer & Sweller 2005). Intrinsic cognitive load is imposed by the learning content itself. The amount or complexity of the information being taught, or the element interactivity,

involves the nature of the learning material and the expertise level of the learner, which together, define the level of intrinsic load placed on the individual (Paas *et al.* 2003). Originally, it was thought that intrinsic cognitive load was resistant to external manipulation; however, recent work has posited that it can be reduced by scaffolding the information, or adapting the level of instructional guidance to the learner's level of expertise (Kalyuga *et al.* 2003; van Merriënboer & Sweller 2005; Kalyuga 2007). Extraneous cognitive load is imposed by information irrelevant to the learning, and thus, places an unnecessary demand on the learner's WM (Paas *et al.* 2003). Extraneous load is often the result of poorly designed instruction. Finally, germane cognitive load is the amount of resources devoted to the development and acquisition of schemas. It is not inherent to the content being taught, but nonetheless aids in the learning process (Paas *et al.* 2003). This type of load is beneficial, presenting information to learners in a way that promotes the development and automation of schemas. It is influenced by instructional design of the learning material and activities, and the presentation of information to be grouped together and organized in LTM.

The way in which the learning material is presented to the learner, or the instructional design, affects how the learner perceives the information. Poor designs include many extraneous, or distracting, elements while information presented in relevant and germane ways promote the efficient acquisition of information. Therefore, the goal of optimizing cognitive load on WM can be accomplished by: (a) minimizing extraneous cognitive load; (b) maximizing germane cognitive load; and (c) optimizing (increase/decrease as needed) intrinsic cognitive load. In other words, the goal of learning is to balance cognitive load by maximizing the portion of germane and intrinsic load, and simultaneously reducing or extinguishing extraneous load (Paas *et al.* 2004).

To compare instructional strategies, CLT researchers have developed a mathematical formula by which instructional efficiency can be measured. Instructional efficiency is defined as the combination of mental effort and performance. It describes how much effort is required, by a learner, to achieve a certain level of performance: 'In this approach, high-task performance associated with low effort is called *high-instructional efficiency*, whereas low-task performance with high effort is called *low-instructional efficiency*' (Paas *et al.*

2003, p. 67). With respect to instructional design, CLT-based recommendations generally place the responsibility on the tutor to adapt instructional guidance to the expertise level of the learner in order to optimize knowledge acquisition and assimilation into LTM (Sweller *et al.* 1998; van Merriënboer & Ayres 2005; van Merriënboer & Sweller 2005; Kirschner *et al.* 2006). However, the extent to which such techniques result in deeper learning and understanding is unclear.

One argument against CLT is its focus on the acquisition of declarative or procedural knowledge in well-structured environments (van Merriënboer & Sweller 2005). However, in less structured environments, where learners must determine the information that needs to be acquired and correct responses are not so straightforward, learners must integrate their acquired knowledge from many sources and apply it to far-transfer tasks. Far transfer tasks require learners to apply knowledge to situations that are dissimilar to their initial learning experience (Haskell 2001). For example, in a study completed by van Merriënboer *et al.* (2002) participants were required to apply their knowledge gained in one computer language to a different computer language. For these types of tasks, instructional strategies are needed that teach conceptual knowledge and integrated knowledge in less structured learning environments (van Merriënboer & Sweller 2005).

### Constructivist theories

Constructivist approaches are numerous and varied, but all share the common theme that learning is best understood, stored, and applied when learners develop their own mental models of the information. Constructivists believe that learners must actively and profoundly process novel information in order to contextually integrate it with their prior knowledge and promote deep learning (Vygotsky 1978; Hein 1991; Jonassen 1999; Taber 2006; Loyens & Gijbels 2008). Constructivism-based instructional goals often include providing the learner with skills or support (e.g. modeling, coaching, scaffolding) and encouraging the learner to actively construct his or her own personal learning experience (e.g. exploration, articulation, reflection) (Jonassen 1999). Thus, the overarching goal is to aid the learner in constructing his or her own model of the information rather than simply providing that information to the learner (Renkl & Atkinson 2007).

Several instructional approaches fall under the umbrella of constructivism (Hein 1991; Jonassen 1999; Kirschner *et al.*, 2006; Taber 2006; Hmelo-Silver *et al.*, 2007; Kuhn 2007; Schmidt *et al.* 2007; Loyens & Gijbels 2008). One such approach, and the focus of this paper, is problem-based learning (PBL; Hmelo-Silver *et al.* 2007). PBL has demonstrated effectiveness in supporting problem-solving that requires the integration of information (Hmelo 1998; Dochy *et al.* 2003; Capon & Kuhn 2004; Derry *et al.* 2006; Mergendoller *et al.* 2006; Norman *et al.* 1994 in Hmelo-Silver *et al.* 2007; Vernon & Blake 1993 in Hmelo-Silver *et al.* 2007). In PBL, learners engage in collaborative problem solving and employ self-directed inquiry and personal reflection in order to develop content strategies and improve learning (Hmelo-Silver *et al.* 2007). This is typically accomplished through strategies such as direct instruction or scaffolding. Direct instruction provides 'just-in-time' information to learners; that is, the information is provided when the instructor believes the learner is capable of understanding and integrating it. Direct instruction has been shown to support knowledge construction and aid in the acquisition of necessary information for future use in other contexts (Adams & Engelmann 1996; Hmelo-Silver *et al.* 2007). Scaffolding involves providing instructional guidance just beyond what the learner is capable of doing independently. Higher-level instruction is simultaneously added while lower-level instruction is removed in an attempt to keep learners in their zone of proximal development (Vygotsky 1978; Verenikina 2003). The empirical literature supports the use of scaffolding, as research has demonstrated it facilitates better integration of knowledge and development of problem-solving skills (Hmelo & Guzdial 1996; Jackson *et al.* 1996; Davis & Linn 2000; Linn 2000; Reiser 2004).

A major argument against constructivist approaches, and PBL in particular, is that they fail to consider efficiency in learning and human cognitive architecture (Kirschner *et al.* 2006). Specifically, there is concern that by allowing learners to construct their own learning experience, the finite capacity of WM will be overloaded and learning will be compromised. In other words, when novice learners attempt to determine what information is important and which information can be considered later or ignored, their lack of the knowledge and experience hinders their ability to distinguish between the two. Consequently, much erroneous infor-

mation will be acquired and germane information may be lost.

### Learning and instructional efficiency

In the absence of a consensus between these two theoretical positions, it is unclear which theoretical approach is more compatible with the military's need to provide both rapid and profound knowledge acquisition. Traditional training that focuses solely on managing cognitive load and neglects the importance of complex learning is not likely to provide the higher-order comprehension required in the modern battlefield. However, training that does not take into account the limitations of WM, imposes excessive extraneous cognitive load, and fails to optimize the capacity available in WM with germane and intrinsic load, is also inadequate, as time and financial resources are limited. Thus, the concept of instructional efficiency, defined as training that imposes little cognitive load and yields high performance results (Sweller *et al.* 1998), must be the goal in military training. Instructional efficiency is a composite calculation of performance and mental effort during performance, which was originally mathematically defined by Paas & van Merriënboer (1993) as performance and mental effort on the 'test' or the outcome of performance.

### Previous findings

Several studies have investigated the differential impact of CLT and constructivist approaches on learning efficiency, yielding equivocal results. Specifically, Charney *et al.* (1990) investigated the use of tutorial, problem solving, and exploration tasks to teach learners a computer application (spreadsheet programme). While the tutorial group demonstrated the fastest training time, when performance time with the correct solution was considered, the problem solving group was superior. Similarly, Paas (1992) compared groups receiving conventional, worked-out, and completion problem tasks; he found that the worked-out and completion groups demonstrated the highest far-transfer performance scores compared with the conventional group. Furthermore, the perceived mental effort required to complete the transfer tasks was lowest in the worked-out and completion groups, suggesting that these strategies have relatively higher

instructional efficiency for far-transfer tasks. In contrast, however, Tuovinen and Sweller (1999) compared exploration tasks and worked-examples to teach how to use a database programme. In this study, novices benefited significantly from the worked-examples problem sets while those with previous experience performed equally well across both conditions, suggesting an 'expertise reversal effect', or a situation where novices benefited from instructional support but those with more experience were not positively influenced (Kalyuga *et al.* 2003). Additionally, van Gog *et al.* (2008) compared process-oriented and product-oriented worked-examples for novices, finding that process-oriented worked-examples imposed effective cognitive load, or germane load, but for those with experience, the same information proved redundant and was consequently identified as ineffective, or extraneous, cognitive load. Collectively, these studies suggest that worked-examples yield better results compared with exploration, but problem-solving or completion tasks further improve learning beyond traditional worked-examples (Atkinson *et al.* 2000). However, the type of worked-example used (process or product-oriented) further complicates these findings, suggesting that the way in which worked-examples are presented can improve their effectiveness. What remains unclear is whether process-oriented worked-examples or completion tasks are more effective and efficient for novice learning.

### Current study

The current study investigates the relative utility of CLT and constructivist-based approaches for teaching complex skills using a military command and control task. Task training consists of constructivist-based instruction (CON) (active learning task), CLT-based instruction (process-oriented worked-example) matched in duration to the constructivist group to control for instruction and exposure time (CLT-C), or CLT-based instruction not matched on time to reflect real-world application [constructivist-based instruction – untimed (CLT-U)]. Outcomes are evaluated for procedural, declarative, conceptual, and integrated knowledge acquisition, as well as decision-making ability. In order to investigate the longevity of these effects, outcome data are assessed both immediately following instruction and after a delay ranging from seven to 11 days.

Finally, instructional efficiency was calculated, both during learning as well as during the performance phase.

Based on the literature reviewed, several strengths and weaknesses of each theory are noted. Specifically, CON emphasizes the importance of the learner taking responsibility for, and being heavily involved in, his or her learning experience. Consequently, it is expected that this type of instruction may lead to stronger conceptual knowledge, integrated knowledge, and decision-making skills. However, when learners are novices, they have little information to guide their learning experience. Consequently, it is expected that their ability to acquire and assimilate incoming novel information will be limited by their lack of domain knowledge resulting in a less efficient learning experience. Alternatively, CLT-based instruction (both CLT-C and CLT-U) emphasizes the acquisition of knowledge while simultaneously managing or optimizing cognitive load during learning. Consequently, more guidance from experts or computer tutoring systems is often provided. In this case, it is expected that the learning experience will be a more efficient process. However, little research has been focused upon the acquisition of higher-order cognitive skills. Furthermore, the expertise reversal effect (Kalyuga *et al.* 2003) suggests that as learners attain expertise, the impact of CLT-based approaches diminishes or is even problematic. Thus, it is possible that this type of approach may be most impactful when teaching procedural and declarative knowledge but less impactful when teaching higher-order cognitive skills that typically require more domain expertise. The ultimate goal of this study is to investigate the impact of each of these approaches on efficient knowledge acquisition within a computer-assisted learning environment (specifically, an SBT system).

### Method

#### Participants

Initially, 292 students enrolled in undergraduate psychology courses elected to participate in the current study in exchange for extra credit towards their respective courses. Of these participants, two reported prior knowledge of the information to be learned, 40 reported they did not watch all the training material as instructed, 134 did not return for Time 2 procedures within the allotted time frame provided, and 38 did not spend the minimum time required to watch all the trainers and



complete all the tasks. Thus, the final sample used in data analysis was composed of 78 [20 male and 58 female, with ages ranging from 18 to 36,  $\mu = 20.12$ , standard deviation (SD) = 2.55] participants.

## Apparatus

### *Simulation Tasks*

*Threat-Assessment Training System (ThreATS)*. ThreATS (Vogel-Walcutt & Nicholson 2009) is a tutorial used to familiarize participants with the United States Marine Corps' Deployable Virtual Training Environment (DVTE) simulator. ThreATS consists of a series of videos, including an introductory component and two additional levels of instruction focused on decisions participants must make while using the DVTE. Specifically, ThreATS teaches participants about the job of a Fire Support Team (FiST), with a particular emphasis on the role of the Forward Observer – Artillery during the Call For Fire (CFF) task.

*Decision-Making Assessment (DMA)*. The DMA requires participants to engage in simulated 'Call For Fire' (CFF) scenarios during four separate phases: two training levels (DMA-T1 and DMA-T2) and two assessments (equivalent in complexity to level 2 training) (DMA-A1 and DMA-A2). Each scenario presents participants with a battlefield containing friendly and enemy targets that are either stationary or moving. Participants must determine the threat level of the targets and subsequently decide the correct sequence in which the targets should be destroyed.

### *Measures*

*Biographical questionnaire*. This 14-item questionnaire addresses personal identifiers such as age, race, gender, military experience, and degree of comfort with and frequency of use of computers.

*Cognitive Load Questionnaire (CLQ)*. The CLQ (Paas 1992) is a single-item measure of perceived cognitive load during a task or set of tasks. Participants rate subjective impressions of mental exertion on a 9-point Likert-type scale, with higher scores indicating greater perceived cognitive load.

*Declarative Knowledge Test (DKT)*. Developed for use in the current study, the DKT consists of 10 factually based multiple-choice items designed to assess the extent to which the participant understands (1) how to determine the correct pieces of equipment that should

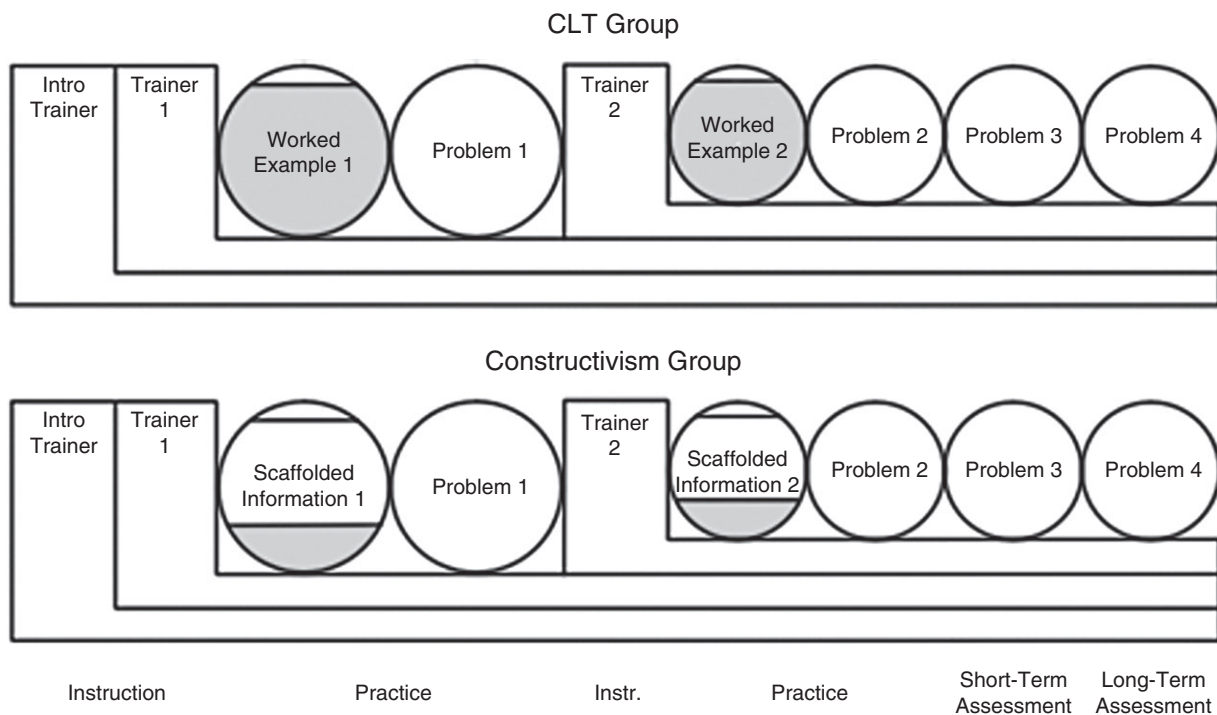
be used to accomplish a certain step in the procedure; and (2) how to use them. For example, 'In this simulation, which piece of equipment would a Forward Observer Artillery use to alert his support team about a target's location'? One point is assigned for each correct response, with a higher score indicating greater declarative knowledge about the task.

*Procedural Knowledge Test (PKT)*. Developed for use in the current study, the PKT consists of eight factually based multiple-choice items designed to assess the extent to which the participant understands the proper execution of a CFF task. Questions inquire about the correct procedure to follow for completion of a particular task and the correct pieces of equipment that should be used to accomplish a certain step in the procedure. For example, 'In this simulation, what is the order in which a Forward Observer Artillery should communicate with the artillery team when calling for fire?' One point is assigned for each correct response, with a higher score indicating greater procedural knowledge about the task.

*Conceptual Knowledge Test (CKT)*. Developed for use in the current study, the CKT is comprised of ten factually-based multiple-choice items designed to assess conceptual knowledge regarding the relationships among members of the FiST, such as which support team each FiST member communicates with and how the tasks are divided among the different members of the FiST. For example, 'Why does it take a while for munitions to achieve the given coordinates once the fire has been ordered?' One point is assigned for each correct response, with a higher score indicating greater comprehension of the task.

*Integrated Knowledge Test (IKT)*. Developed for use in the current study, the IKT is comprised of nine free-response items designed to assess inferences about and deeper knowledge of the FiST. The questions present situations a FiST member might encounter that are not explicitly mentioned in the training presentations, requiring participants to apply their conceptual knowledge to novel situations. The IKT is scored by trained raters using a coding rubric. Each item is worth a maximum of three points, with intermediate credit assigned for partial or incomplete answers. Higher scores on the IKT are reflective of greater integrated knowledge regarding the task and simulator.

*Decision Making (DM)*. Decision-making scores were based on performance in decision-making assessment



**Fig 1** Instructional designs tested. \*The shaded area represents how much support was provided by each approach when guiding participants through the problem: the worked problem approach [cognitive load theory (CLT)] provided more explicit information than the scaffolded information (constructivism), leaving little to be constructed by participants on their own.

scenarios and calculated to indicate overall decision-making skills across the full assessment. Targets were rank-ordered *a priori* to indicate the best neutralization sequence. This ranking was based on the differential levels of threat of each target (as described in ThreATS). Decisions were awarded increasingly higher penalty points according to this ranking, with the best decisions (i.e. destroying the right enemy target at the right time) acquiring no points and the worst decisions (i.e. destroying a friendly target) receiving as many as 16 points. These individual scores were then averaged across the number of decisions made.

#### Procedure

The study was conducted online and consisted of two discrete portions, each occurring 7–11 days apart. After providing informed consent, participants completed the biographical questionnaire and then participated in one of three randomly-assigned training conditions (CLT-C, CLT-U, or CON). In the CLT conditions (CLT-C and CLT-U), the audio guided participants through the problem in a worked-example format. The

process-product instantiation method (van Gog *et al.* 2007) was used to provide audio-taped instruction regarding optimal neutralization of the battlefield. This method involves first providing instruction using the process-oriented approach of supplying the rationale for the solution, and eventually switching to the product-oriented approach of providing the solution only. In the constructivist-based condition (CON), audio instruction guided participants through the problem utilizing scaffolding procedures. Audio statements guided and probed participants about how to optimally neutralize the battlefield. As participants progressed through the training, the questions evolved from focusing on lower-level knowledge (target recognition) to focusing on integrated knowledge (the impact of decisions in this battlefield on other battlefields).

The CLT and Constructivism versions of the first practice problem are represented in Fig 1. After receiving instruction, participants completed an introductory experience designed to familiarize the individual with the CFF task, followed by two complete learning cycles. Both cycles followed a similar pattern. First,

participants watched a ThreATS video. At the conclusion of the video, participants were shown a picture of a battlefield depicting eight (level 1 ThrEATS) or sixteen (level 2 ThrEATS) friendly and enemy targets. They then completed a CLQ regarding their perceived level of effort to learn the presented material. Next, participants completed the decision making assessment (DMA-T1 or DMA-T2) to determine their ability to apply the learned information, after which they completed a CLQ regarding the scenario. Participants then filled out the knowledge tests (the IKT was administered during the second cycle only). Following the completion of these measures, the CLQ was administered regarding the participants' experience completing the knowledge tests. Finally, participants completed DMA-A1. After seven to eleven days, participants completed DMA-A2, a CLQ regarding DMA-A2, the DKT, PKT, CKT, and IKT, followed by a final CLQ regarding the knowledge tests.

## Results

### Preliminary data analyses

Data were analyzed using SPSS 17.0 for Windows. Missing data were deleted listwise from analyses. Means and standard deviations for variables of interest are provided in Table 1.

### Results by Hypothesis

#### CON

Due to the small sample size and because the assumption of sphericity was met, a univariate approach was used for this analysis. Thus, to examine the effect of the training on the outcome measures, separate 3 (group)  $\times$  2 (time) mixed model univariate analyses of variance (ANOVA) were conducted. Contrary to our hypotheses, no significant interaction effect was found for the CKT ( $F [2, 74] = 0.09, P = 0.913$ , partial  $\eta^2 = 0.002$ ) or the IKT ( $F [2, 69] = 1.03, P = 0.362$ , partial  $\eta^2 = 0.03$ ), or DM ( $F [2, 65] = 2.26, P = 0.113$ , partial  $\eta^2 = 0.07$ ). Based on a priori hypotheses, post-hoc pairwise comparisons were conducted. Results revealed no significant differences for CKT or DM, at either the immediate or delayed assessment times. However, for the IKT, the comparisons revealed that CLT-C had significantly higher scores than CON during the delayed assessment ( $\Delta\bar{x} = 1.72, P = 0.005$ ). This

**Table 1.** Means and SDs of knowledge tests and decision-making scores by group and time.

	Group	Time	M	SD
DKT <sup>1</sup>	CLT-C	Immediate	6.96	1.62
		Delayed	6.88	1.81
	CLT-U	Immediate	6.46	1.77
		Delayed	6.33	2.16
	CON	Immediate	6.64	1.64
		Delayed	6.18	1.68
PKT <sup>1</sup>	CLT-C	Immediate	11.24	3.66
		Delayed	10.92	3.86
	CLT-U	Immediate	11.71	5.15
		Delayed	11.58	4.75
	CON	Immediate	10.79	3.70
		Delayed	10.32	3.67
CKT <sup>1</sup>	CLT-C	Immediate	6.04	2.07
		Delayed	5.84	1.91
	CLT-U	Immediate	6.00	2.55
		Delayed	6.00	1.93
	CON	Immediate	5.54	2.37
		Delayed	5.43	2.38
IKT <sup>2</sup>	CLT-C	Immediate	6.72	2.44
		Delayed	6.92	1.48
	CLT-U	Immediate	5.70	2.03
		Delayed	5.82	2.50
	CON	Immediate	5.56	1.72
		Delayed	5.20	1.48
DM <sup>3</sup>	CLT-C	Immediate	-2.00	2.39
		Delayed	-1.49	2.00
	CLT-U	Immediate	-2.29	2.71
		Delayed	-2.49	3.07
	CON	Immediate	-2.84	2.26
		Delayed	-3.40	2.07
EFF <sup>4</sup>	CLT-C	ThrEATS1	0.19	0.18
		ThrEATS 2	-0.19	0.18
		Immediate	-0.16	0.17
		Delayed	0.25	0.19
	CLT-U	ThrEATS 1	-0.07	0.18
		ThrEATS 2	0.19	0.18
		Immediate	-0.05	0.17
		Delayed	-0.14	0.20
	CON	ThrEATS 1	0.05	0.17
		ThrEATS 2	-0.24	0.17
		Immediate	-0.21	0.16
		Delayed	-0.12	0.18
CLQ <sup>4</sup>	CLT-C	Immediate	6.46	1.30
		Delayed	5.62	1.94
	CLT-U	Immediate	6.04	1.55
		Delayed	6.17	1.58
	CON	Immediate	5.89	1.42
		Delayed	5.64	1.42

Note. *N* (listwise) = 77<sup>1</sup>; 72<sup>2</sup>; 68<sup>3</sup>; 78<sup>4</sup>.

DKT, Declarative Knowledge Test; PKT, Procedural Knowledge Test; CKT, Conceptual Knowledge Test; IKT, Integrated Knowledge Test; DM, decision-making; EFF, efficiency; CLQ, Cognitive Load Questionnaire; CLT-C, cognitive load theory-control; CLT-U, constructivist-based instruction – untimed; CON, constructivist-based instruction.



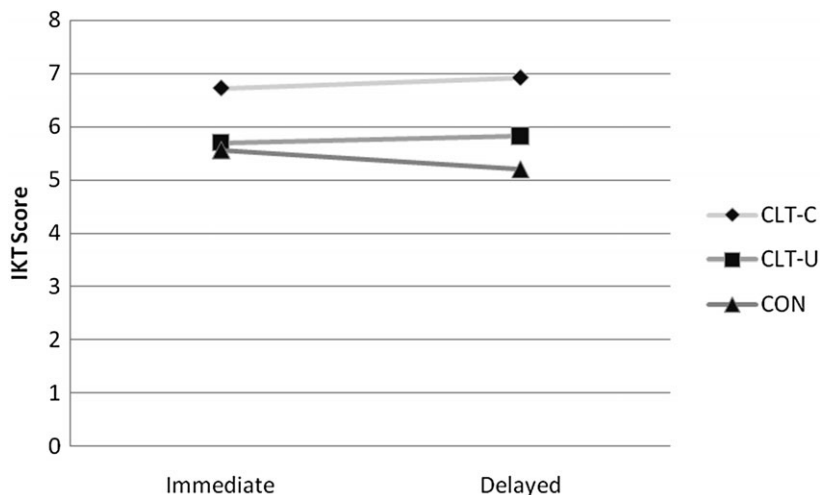


Fig 2 Interaction between group and time on IKT. IKT, Integrated Knowledge Test; CLT-C, cognitive load theory-control; CLT-U, constructivist-based instruction – untimed; CON, constructivist-based instruction.

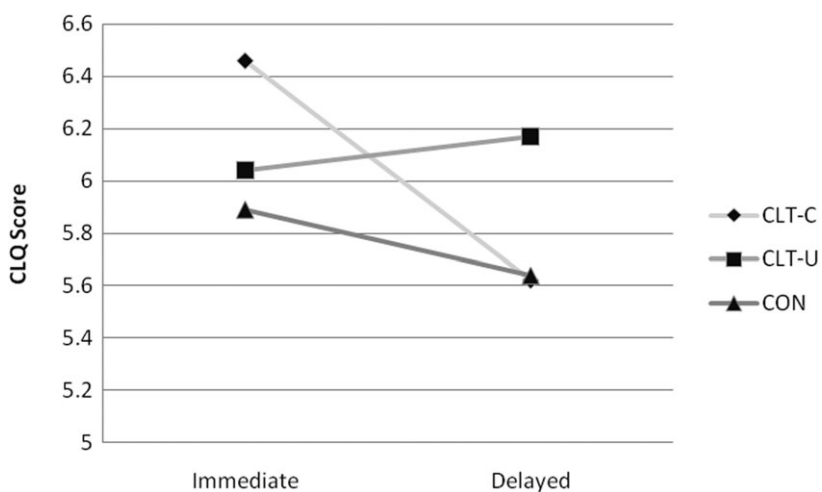


Fig 3 Interaction between group and time on CLQ. CLQ, Cognitive Load Questionnaire; CLT-C, cognitive load theory-control; CLT-U, constructivist-based instruction – untimed; CON, constructivist-based instruction.

was not the case at the assessment that occurred immediately following instruction (see Fig 2).

*CLT-based instruction (both CLT-C and CLT-U)*

Individual 3 × 2 mixed model ANOVAs were again conducted to investigate this hypothesis. Contrary to our hypothesis, no significant interaction effect was found for the DKT ( $F [2, 74] = 0.68, P = 0.512$ , partial  $\eta^2 = 0.02$ ) or PKT ( $F [2, 74] = 0.11, P = 0.896$ , partial  $\eta^2 = 0.003$ ). Pairwise comparisons revealed no significant differences for either of these measures at either assessment time.

*Cognitive load*

A 3(group) × 2(time) mixed model ANOVA was conducted to investigate changes in cognitive load over time. Significant differences were found between

groups ( $F [2, 75] = 3.73, P = 0.028$ , partial  $\eta^2 = 0.091$ ). Based on a priori hypotheses, *post hoc* pairwise comparisons were conducted. The comparisons revealed that CLT-C reported a significantly greater decrease in cognitive load from time one to time two than CLT-U ( $\Delta\bar{x} = 0.846, P = 0.001$ ) (see Fig 3). No other significant differences were noted.

*Instructional efficiency*

Instructional efficiency was calculated using the following formula (Paas & van Merriënboer 1993):

$$\text{Efficiency} = \frac{(zP_{\text{test}} - zE_{\text{test}})}{\sqrt{2}}$$

A 3 (group) × 2 [time: Training (ThrEATS level 1 and ThrEATS level 2) and Assessment (immediate assess-

ment and delayed assessment] mixed model ANOVA was conducted to investigate this hypothesis. Contrary to our hypothesis, no significant interaction effect was found for training efficiency (ThrEATS level 1, ThrEATS level 2) ( $F [2,75] = 2.33$ ,  $P = 0.10$ , partial  $\eta^2 = 0.06$ ) or performance efficiency ( $F [2,75] = 2.49$ ,  $P = 0.09$ , partial  $\eta^2 = 0.06$ ). *Post hoc* pairwise Comparisons within each timeframe revealed a significant difference for those in Group 1 to have greater efficiency at Time 2a (immediate assessment) than they did at Time 2b (delayed assessment) ( $\Delta\bar{x} = 0.40$ ,  $P = 0.01$ ). No other significant differences were noted.

## Discussion

The goal of this study was two-fold. First, we compared the extent to which CLT and constructivist-based approaches influence learners' abilities to acquire both lower-level (procedural, declarative) and higher-order (conceptual, integrated, and decision-making) knowledge. A secondary objective was to examine the extent to which these instructional supports promote the efficient acquisition and application of that information within a computer-assisted learning environment.

Findings suggest that the acquisition of procedural, declarative, and conceptual knowledge, as well as decision-making skills, did not differ as a function of the type of instruction used. However, integrated knowledge was slightly better retained by the group provided with worked-examples and given additional time to review the problem results. These results are contrary to our expectation that constructivist approaches, which focus on the development and integration of information, would yield better performance in an applied problem-based environment. Thus, while contemporary researchers continue to defend the use of PBL strategies for teaching (Hmelo-Silver *et al.* 2007), our research supports earlier findings that question the utility, efficiency, and impact of PBL strategies in applied domains (Albanese & Mitchell 1993; Berkson 1993). Specifically, previous research supporting the use of PBL's strategies was often based upon results from non-traditional assessments such as a comparison of the number of hypotheses generated during problem-solving or the creativity of participants' diagnosis process in a medical setting, but not based on the accuracy of their skills (Patel & Groen 1986; Berkson 1993; Hmelo *et al.* 1997; Norman *et al.* 2000; Capon & Kuhn

2004; Mergendoller *et al.* 2006). Furthermore, those using traditional, performance-based testing report equivocal findings (Albanese & Mitchell 1993; Berkson 1993). It is with these latter studies that our research agrees. Our findings, based on results of multiple types of knowledge, demonstrate a preference for neither group except in the retention of integrated knowledge. Such results encourage consideration of cost, ease of delivery, and teaching time required. The resource burden imposed by constructivist approaches, coupled with the lack of empirical support, makes it difficult to recommend its use with this population, at least when time is held constant and the learners are novices.

Based on the theoretical underpinnings of CLT, these results may indicate that participants lacked the motivation required to attend to, or their working memories were overloaded by, the more extensive and thought-provoking information provided in the CON. As a result, task shedding occurred and participants learned less than those receiving CLT-based instruction. It remains unclear, however, if these results would differ as learners progress towards expertise. Previous research suggests that as learners become more proficient, differential strategy impacts occur (van Gog *et al.* 2005; van Merriënboer & Sweller 2005; Kalyuga 2007).

Supporting our hypotheses, however, findings suggest that efficiency was improved when CLT-supported instruction was used compared with the constructivist approach. Specifically two analyses were conducted to consider the effects of the different instructional types on the efficiency of knowledge acquisition and retention. The group that was provided a worked-example with additional review time demonstrated the highest efficiency. However, the effect size (ES) was very low ( $ES = 0.04$ ) suggesting that, while significant mathematical differences were found between the groups provided with worked-examples and the group provided with scaffolded guidance, these differences will not likely translate to practical significance. Therefore, predominately, CLT and constructivist approaches were equivalent across knowledge types, but CLT approaches proved more efficient both immediately and 1 week later.

Accordingly, these data help provide a rationale and consequent recommendations for building computer-assisted learning environments, whether in the form of SBT for the military or in the form of computer-based

training for K-12 education. Specifically, as noted above, the time and monetary cost of creating programmes that utilize problem-based approaches are generally greater than those programmes focused on teaching information in a straightforward manner. Problem-based approaches need to be free-flowing and allow learners to navigate many different sequences or 'locations'. Alternatively, computer environments that require learners to follow a pre-planned procedure (e.g. worked-example) require less time and cost to create usable programmes. Thus, these data provide some initial support for the creation of prescribed, learning focused programmes that utilize principles from either theory but pragmatically, relying more on CLT-based processes will likely yield less costly, yet equally effective, programmes.

Future research in this area should investigate the use of other strategies supported by these fields. In this experiment, we investigated only one strategy of the many that both paradigms endorse. As such, it is premature to conclude that one approach is more impactful. For example, Mayer (2005) summarizes a list of principles derived from CLT and applied to multimedia environments. These principles of learning efficiency could be further examined in the context of higher-order cognitive skills and possibly again compared with other strategies supported by constructivist theories. Another area of consideration is the impact of these approaches on non-novice participants. The 'expertise-reversal effect', a phenomenon whereby learners who are higher on the expertise continuum require different teaching strategies to maintain impact, is commonly discussed, but less often empirically tested (Kalyuga 2007). While this may typically be due to the difficulty in attaining non-novice populations for experimentation, the need to investigate the ways in which CLT and constructivist paradigms impact these learners is needed.

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