



Defence Research and
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Recherche et développement
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Suitable Adaptation Mechanisms for Intelligent Tutoring Technologies

*Ming Hou and Suzanna Sobieraj
DRDC Toronto*

*Chelsea Kramer, Jana Lee Tryan, Simon Banbury, and Kristine Osgoode
CAE Professional Services Canada*

Defence R&D Canada
Technical Report
DRDC Toronto TR 2010-074
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Canada

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Principal Author

Original signed by Dr. Ming Hou

Dr. Ming Hou

Group Leader, Advanced Interface Group

Approved by

Original signed by Linda Bossi

Linda Bossi

Head, Human Systems Integration Section

Approved for release by

Original signed by H. Duggal

H. Duggal

for Chair, Knowledge and Information Management Committee

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Abstract

This report summarizes the results of a literature review conducted to recommend suitable adaptation mechanisms for an intelligent tutoring system (ITS). Intelligent Tutoring technologies have been identified by Defence Research & Development Canada (DRDC) – Toronto as an effective training aid for the Canadian Forces (CF). A specific CF training course, the Improvised Explosive Device Disposal (IEDD) Operator Course, has been identified as a target for the implementation and evaluation of intelligent tutoring technologies. The review involved surveying and synthesizing applicable literature to develop recommendations and best practices pertaining to the integration of these technologies into an ITS for the IEDD Operator Course to improve questioning skills. The recommended four adaptation mechanisms for implementation into the IEDD ITS were as follows:

- Eye-tracking technologies to support attention tracking;
- Cognitive learning styles to support customization of the learning environment;
- Psychophysiological indices to support cognitive state monitoring; and
- Performance measures to support engagement tracking.

Résumé

Le rapport présente les résultats d'une analyse documentaire visant à recommander des mécanismes d'adaptation appropriés pour un système tutoriel intelligent (STI). Des technologies de tutorat intelligent ont été déterminées par Recherche et développement pour la défense Canada (RDDC) – Toronto en tant qu'outil efficace d'aide à l'instruction des Forces canadiennes (FC). Un cours particulier d'instruction des FC, le Cours d'opérateur de la neutralisation des engins explosifs improvisés (IEDD), a été identifié comme convenant à la mise en œuvre et à l'évaluation des technologies de tutorat intelligent. L'analyse consistait à étudier et à résumer les documents pertinents afin de formuler des recommandations ainsi que d'établir les meilleures pratiques relatives à l'intégration de ces technologies en un système tutoriel intelligent pour le Cours d'opérateur IEDD afin d'améliorer les aptitudes d'interrogation. Les quatre mécanismes d'adaptation que l'on propose de mettre en œuvre dans le STI IEDD sont les suivants :

- technologies de suivi du regard à l'appui du suivi de l'attention;
- styles d'apprentissage cognitif à l'appui de l'adaptation de l'environnement d'apprentissage;
- indices psychophysiologiques à l'appui du suivi de l'état cognitif;
- indicateurs de rendement à l'appui du suivi de l'engagement.

Executive summary

Suitable Adaptation Mechanisms for Intelligent Tutoring Technologies:

Ming Hou, Suzanna Sobieraj, Chelsea Kramer, Jana Lee Tryan, Simon Banbury, and Kristine Osgoode; DRDC Toronto TR 2010-074; Defence R&D Canada – Toronto; December 2010.

This document presents the results of a literature review conducted to recommend specific intelligent tutoring technologies for integration into a Canadian Forces (CF) training course. Previous research efforts have identified a specific CF training course, the Improvised Explosive Device Disposal (IEDD) Operator Course as a target for the implementation and evaluation of intelligent tutoring technologies. Importantly, in the IEDD training course the failure rate for the team leader is significantly high (40%). This failure rate has been attributed to deficiencies in students' threat assessment and questioning technique skills.

The objective of this review was to identify suitable adaptation mechanisms that could be used to improve the effectiveness of an intelligent tutoring system (ITS), which will be implemented within the IEDD Operator Course. The ITS can customize training material and provide real-time feedback to improve students' questioning skills. A large body of knowledge was surveyed and synthesized to develop recommendations and highlight best practices. Scientific, defence, government, and internet-based sources were searched for literature pertaining to principles and best practices for adaptation mechanisms in an ITS. The emphasis of the search was to find developing and maturing technologies (e.g., Commercial Off-The-Shelf (COTS) products) instead of theoretical or conceptual insights.

The results of the literature review demonstrated a range of maturing technologies that can be applied to the ITS designed to augment the IEDD Operator Course. The recommended technologies for implementation into the IEDD ITS are as follows:

- Eye-tracking technologies to support attention tracking;
- Cognitive learning styles to support customization of the learning environment;
- Psychophysiological indices to support monitoring cognitive states (e.g., workload); and
- Performance measures to support engagement tracking.

Sommaire

Suitable Adaptation Mechanisms for Intelligent Tutoring Technologies:

Ming Hou, Suzanna Sobieraj, Chelsea Kramer, Jana Lee Tryan, Simon Banbury, and Kristine Osgoode; DRDC Toronto TR 2010-074; R & D pour la défense Canada – Toronto; Décembre 2010.

Ce document présente les résultats d'une analyse documentaire visant à recommander des technologies particulières de tutorat intelligent à intégrer dans un cours de formation des Forces canadiennes (FC). Des recherches antérieures ont permis de déterminer un cours particulier des FC, soit le cours d'opérateur de la neutralisation des engins explosifs improvisés (IEDD), en tant que cible pour la mise en œuvre et l'évaluation des technologies de tutorat intelligent. Fait important, dans le cours de formation IEDD, le taux d'échec pour le chef d'équipe est très élevé (40 p. 100). Ce taux d'échec a été attribué aux compétences insuffisantes des stagiaires en matière d'évaluation des menaces et d'interrogation.

L'analyse documentaire avait pour objet de trouver des mécanismes d'adaptation utiles pouvant servir à améliorer l'efficacité d'un système tutoriel intelligent qui sera mis en œuvre dans le cadre du cours d'opérateur IEDD. Le STI peut adapter le matériel de formation et offrir une rétroaction en temps réel afin d'améliorer les techniques d'interrogation des stagiaires. Un vaste ensemble de connaissances a été analysé et résumé afin de formuler des recommandations et de souligner les pratiques exemplaires. On a effectué des recherches dans des sources scientifiques, de la défense, du gouvernement et d'Internet afin de trouver de la documentation sur les principes et les pratiques exemplaires relatifs aux mécanismes d'adaptation dans un STI. Le but principal de la recherche était de trouver des technologies en voie d'évolution et de maturation (p. ex., des produits logiciels commerciaux) et non des considérations théoriques et conceptuelles.

Selon les résultats de l'analyse documentaire, une gamme de technologies en voie de maturation peuvent être appliquées au STI conçu pour compléter le cours d'opérateur IEDD. Voici les technologies que l'on recommande d'intégrer au système tutoriel intelligent en matière d'IEDD :

- technologies de suivi du regard à l'appui du suivi de l'attention;
- styles d'apprentissage cognitif à l'appui de l'adaptation de l'environnement d'apprentissage;
- indices psychophysiologiques à l'appui du suivi des états cognitifs (p. ex., la charge de travail);
- indicateurs de rendement à l'appui du suivi de l'engagement.

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1 Introduction

This document presents the results of a literature review conducted to recommend specific intelligent tutoring technologies for integration into Department of National Defence (DND) learning environments in order to improve Canadian Forces (CF) distance learning capabilities. Specifically, a CF training course, the Improvised Explosive Device Disposal (IEDD) Operator Course, has been identified as an ideal target for the implementation, evaluation, and demonstration of intelligent tutoring technologies.

1.1 Background

The IEDD Operator Course teaches CF personnel to identify, disrupt, and dispose of intelligent explosive devices (IEDs). Students are also taught how to identify, recognize, and formulate an accurate threat assessment of the suspected IED, and to provide advice on immediate protective measures against hazards associated with chemical, biological, and radiological (CBR) improvised devices.

At present, the course is delivered using a combination of classroom and field-based training. One of the biggest difficulties associated with the course is gathering the students together for the classroom and scenario-based training. Questioning technique is taught in a classroom setting using a series of text-based PowerPoint slides, which essentially provide definitions of the different types of questions that one could ask (e.g., open-ended, leading, etc.), and when each may or may not be appropriate. Misinterpretation of pertinent cues within the evaluation scenarios can mislead students, causing them to identify an incorrect IED Render Safe Procedure (RSP) and, ultimately, leading them to fail the course.

Currently, the course failure rate for the IEDD team leader is significantly high (40%). This failure rate has been attributed to difficulties during situation assessment and decision-making biases related to working under considerable time pressure and stress. Examples of decision-making biases include confirmation bias and belief perseverance. The former is a tendency to seek data that confirms one's beliefs (Wason, 1960), while the latter is a resistance to changing one's beliefs in the face of disconfirming evidence (Ross, Lepper, & Hubbard, 1975).

Decision-making biases expressly affect the portion of the IED identification process that involves both the close inspection of the device itself, and the gathering of information about the device. This information is achieved through questioning third parties (e.g., civilians, local police, CF personnel, etc.) to determine the level of threat posed to personnel by the device. Therefore, the implementation of intelligent tutoring technologies to improve decision-making processes and situation assessment has been targeted explicitly at the IED identification process.

To address the IEDD high failure rate training problem and to improve trainees' situation assessment and decision-making skills, Defence Research and Development Canada (DRDC) - Toronto has identified intelligent tutoring technologies as a solution.

Intelligent tutoring technologies try to minimize the mismatch between learner needs and the learning environment as they attempt to elicit learner needs via performance measures and explicit modeling practices. However, these systems tend to ignore learner differences (Karamouzis, 2006). The key challenge addressed in this report is the ability to create an ITS that can customize the learning experience to the individual and to incorporate his or her differences.

An Intelligent Tutoring System (ITS) broadly encapsulates any self-regulating computer program that contains some intelligence and can be used for the control, delivery, and assessment of learning content. An ITS is the environment in which adaptation for the learner is accomplished. Thus, complex algorithms are designed to rely on feedback from the learner's performance, prior exposure to knowledge, and learning rate to deliver, evaluate, and react according to pedagogical principles, educational goals, and implementation tools.

The goal of most ITSs is to provide the learner with the same benefits as one-on-one instruction, automatically. While tutoring between an expert and a novice has shown to be a very effective way to learn, computer-based, unsupervised instruction is vulnerable to student disengagement, boredom, frustration, and an overall lack of effective learning (Woodill, 2004). To remedy such deterrents, intelligent tutoring mechanisms must customize the content, format, modality and time of content exposure to the individual's learning style and preferences. Intelligent tutoring systems offer one solution to help to achieve these goals.

In the context of IEDD Operator training, the challenge is for the adaptation mechanisms in an ITS to improve trainees' identification of IEDs, their questioning techniques and threat assessment skills. To address this issue, DRDC Toronto has reviewed a wide range of possible intelligent tutoring technologies and has identified four adaptation mechanisms suitable for implementation in an ITS. They are eye-tracking technologies, cognitive learning styles, psychophysiological indices, and performance/attention tracking. However, details of these adaptation mechanisms still need to be reviewed in terms of their theoretical foundation, validation, best practices, and their feasibility for the ITS (Banbury, Osgoode, Unrau, & Kramer, 2009).

1.2 Objectives

The objective of this review was to identify suitable adaptation mechanisms that could be used to improve the effectiveness of an ITS that will be developed for the IEDD Operator Course. This objective was achieved by combining a sequence of related reviews with current and more detailed information on purchasable technology, in order to provide specific and concrete recommendations on the products that should be purchased and implemented into the IEDD Operator Course ITS. The work described in this report reviews the literature pertaining to principles and best practices for intelligent tutoring technologies as pertaining to operator cognitive state (e.g., workload, stress), learning style, engagement and performance. The results of this review were used to provide recommendations and guidelines for the integration of these technologies into the IEDD ITS.

1.3 Scope

The structure of this document is described below:

- *Section 1.* Presents a brief introduction to the IEDD Operator Course, and an overview of the current research;
- *Section 2.* Presents a detailed description of the review method used for the current research;
- *Section 3.* Presents the results of the survey and review of eye-tracking technologies and provides recommendations for the implementation of these technologies within the realm of the proposed IEDD ITS;
- *Section 4.* Presents the results of the survey and review of cognitive learning styles and provides recommendations for the implementation of these technologies within the realm of the proposed IEDD ITS;
- *Section 5.* Presents the results of the survey and review of psychophysiological indices and provides recommendations for the implementation of these technologies within the realm of the proposed IEDD ITS;
- *Section 6.* Presents the results of the survey and review of performance measures and attention tracking, and provides recommendations for the implementation of these technologies within the realm of the proposed IEDD ITS;
- *Section 7.* Presents overall conclusions, purchasing recommendations, suggestions for future work, and implementation plans with respect to intelligent tutoring.

2 Review Method

This section presents the process for a review of intelligent tutoring technologies which led to recommendations and suggested uses for their implementation to improve CF distance learning capabilities. All recommendations and best practices are geared towards the IEDD Operator Course.

This focus of this report includes the following four adaptation mechanisms and technologies:

- Eye-tracking technologies;
- Cognitive learning styles;
- Psychophysiological indices; and
- Performance measures and attention tracking.

It should be noted that the objective of each review section was to examine studies that have been successful (or at least show potential) at implementing the target adaptation mechanism or technology. Fulfilling this objective was an essential precursor to identifying key factors in the implementation and evaluation of each adaptation mechanism or technology within an ITS for the IEDD Operator Course.

2.1 Literature Search Process and Considerations

Scientific, defence [e.g., United States (US) defence and North Atlantic Treaty Organization reports (NATO)], government (e.g., DRDC archives) and internet-based sources were searched for literature pertaining to the four previously mentioned adaptation mechanisms and technologies. Lone-standing technology products were included to provide greater breadth and depth to the range of technologies used, as journal articles typically feature only the same few mainstream brands. Typically, a university or institution (authoring the articles) will purchase a sole piece of premium technology which is then used by many people. As purchasing the most expensive type of equipment may not be desirable for the current project, it was important to include a range of options within each of the adaptation techniques discussed.

The emphasis of the search was finding developing and maturing technologies [e.g., Commercial-Off-The-Shelf (COTS) products] to measure these characteristics, instead of theoretical/conceptual insights. As such, the review highlights technologies that could potentially be used, or that were used successfully with other types of ITSs.

A further consideration of the review was the ITS context for which this research will be developed. The ultimate goal is to create an ITS to enhance the learning environment and ultimately improve training for the IEDD Operator Course. The current high failure rate (i.e., 40%) is believed to stem from problems in teaching and learning questioning techniques. As a result, the type of technology chosen must cater to training operators within this context.

The task of choosing products based on quality or validated research is further complicated by other constraining factors that will influence the type of technology actually used. In other words, products that are feasible for the project may differ from the “best-available” product in each category. The multiple training environment factors that were considered when conducting the literature search for technologies are presented in *Table 1*.

Table 1. Training environment factors and ITS implementation considerations.

Training Environment	ITS Implementation Considerations
1. Will the user operate the ITS from a laptop or personal computer (PC), or is the training immersive in theatre?	➤ Need to consider wireless options, mobility, fidelity of virtual environment, visibility, lighting
2. Will training occur in a classroom setting with other students, or work individually?	➤ Need to consider distractions, noise-level, attention, and movement
3. How many mechanisms will be used at once?	➤ Need to consider if technologies interfere with one another?
4. Will students work remotely, as a distance learner with limited support?	➤ Tutor will need to be self-sufficient – i.e., able to run without supervision of the researcher or other expert

Considering that the current study will start with threat assessment and questioning technique, which is only a small subset of the course content, this review also considered mechanisms that could benefit the course beyond the ITS itself. For instance, reviewed in detail are suggestions on how training introspective awareness of differences between one’s own learning style from others can improve learning in a classroom setting. The following section describes the process of detailed review for each reference on adaptive mechanisms.

2.2 Review Summary on Adaptation Mechanisms

The following sections detail the most relevant references and technologies pertaining to eye tracking, cognitive learning styles, psychophysiological measures, and attention/performance tracking as means of implementing an ITS. Where relevant, references state the general type of product (e.g., headmounted eye-tracker), brand name (e.g., Tobii™) and software when known (e.g., MatLab™) that were used in the study. The goal was to emphasize the technologies actually

used in published studies. Furthermore, similar technologies that were not used within the context of a published article, but were deemed relevant to the current literature review were included in order to provide more depth (i.e., “comparison shopping”) into the overall search of adaptive mechanisms.

Table 2 shows the categorization of the 73 references included in this review. The number of articles is allocated to each of the four literature sections: Eye-tracking; Cognitive Learning Styles; Psychophysiological Measures; and Performance Tracking. Each literature section begins with a high-level description of the content of the literature and products that were reviewed, followed by a list of the references examined, and a table that summarizes the characteristics of the adaptive mechanisms within the context implementation for the IEDD Operator Course. This summary table is used to infer recommendations for the implementation of these technologies into the IEDD Course.

Table 2. Number of references grouped by literature review topic area

Literature Review Topic Area				
	Eye-Tracking	Learning Styles	Psychophysiological	Performance Tracking
Total Number of References	19	10	30	14

Table 3 describes the number of articles classified in terms of the level of experimentation involved (i.e., conceptual study involving no evaluation, single laboratory-based evaluation, single simulator or field-based evaluation, and multiple laboratory-, field- or simulator-based evaluations), degree of peer review (i.e., none, conference proceedings and/or journal article), and proximity and relevance to military domains (i.e., basic, business, industrial and military).

Table 3. Number of references grouped by level of experimentation, peer review and domain relevance

	Level of Experimentation				Peer Review			Domain Relevance				Stand-Alone Products
	Conceptual	Single Lab Evaluation	Single Simulation or Field	Multiple Evaluations	None	Conference	Journal	Academic	Business	Industrial	Military	COTS
Total Number of References	6	8	17	12	3	17	23	26	1	6	9	21

The statistics shown in the preceding two tables demonstrate that:

- The breadth of articles reviewed is sufficient; a large number of articles have been used in all four topic areas.
- The articles are mostly single field/simulation (23%) or multiple-based studies (16%);
- A significant proportion of articles are peer reviewed (34%); and,
- A significant proportion of the references originate from the academic domain (37%), while 29% are references for “stand-alone” products that are COTS

3 Eye-Tracking

This section provides a brief summary on processes, uses, and types of eye-tracking technology. This review is intended to aid the understanding of the reader, but should not be considered a comprehensive description of all eye-tracking literature.

3.1 Eye-Tracking Processes

Eye-tracking is the process of measuring either the point of gaze ("where we are looking") or the motion of an eye relative to the head. The basic assumption of eye-tracking data is that where the subject is looking is what they are attending to. While this report acknowledges the concept of "*inattentional blindness*" - the phenomenon of not perceiving a stimulus in plain sight (Simons & Chabris, 1999) – further separation of eye-tracking from perception is beyond the scope of this review.

According to Viviani (1990), eye tracking can be used to gain a better understanding of how a visual stimulus is being encoded. Eye movement is typically divided into fixations (i.e., when the eye gaze pauses in a certain position) and saccades (i.e., when the eye moves to another position). The resulting series of fixations and saccades is called a scanpath (Cassin & Solomon, 1990). Perception is considered to occur while the eye is fixated, as opposed to during a saccade (e.g., North, William, Hodges, Ward, & Ericsson, 2009). Essentially, this is based on the premise underlying the eye - mind hypothesis, which states that people look at the object or location that they are thinking about (Just & Carpenter, 1988).

For instance, if an individual is looking at a particular word, it is assumed that they are processing (i.e., reading) that word. In research involving computer interfaces, based on the eye - mind hypothesis, we are able to determine and uncover the most informative areas of a display or scene. As such, we are able to infer what is being processed by computing eye metrics such as dwell time within a defined Area of Interest (AOI) (Rayner, 1998). In addition to dwell time, the sequential nature of eye-movement behaviour has been linked to intent. Brandt and Stark (1997) found evidence supporting sequential processing (scanpath) where they concluded, that an "internalized, cognitive perceptual model must be in control of these scanpaths" (p. 32). In essence, uncovering the sequence of eye-movements from one area of interest to another is valuable in understanding the strategies and planning used by individuals when performing a task, which are often shown to differ among expert and novices in a given area.

The central one or two degrees of the visual angle (the fovea) provide the bulk of visual information; the input from larger eccentricities (the periphery) is less informative. Hence, the locations of fixations along a scanpath show what information loci on the stimulus were processed during an eye-tracking session. On average, fixations last for around 200 ms during the reading of linguistic text, and 350 ms during the viewing of a scene. Preparing a saccade towards a new goal takes around 200 ms (Cassin & Solomon, 1990).

Scanpaths are useful for analyzing cognitive intent, interest, and salience. Other biological factors (e.g., gender) may also affect the scanpath. There are a number of methods for measuring eye movements such as scan paths, but the most commonly used method in research is the eye-tracker

device. The most popular option uses video images from which the eye position is extracted, while other methods are based on the electrooculogram (EOG); a technique for measuring the resting potential of the retina which results in a record of eye movements (e.g., Bulling, Roggen, & Troster, 2008). The following is a brief summary on popular types of eye-trackers used in the literature that was examined in this review.

3.2 Types of Eye-Trackers

The most widely used current designs are video-based eye-trackers. In these types of eye-trackers, a camera focuses on one or both eyes and records their movement as the viewer looks at a stimulus. Most modern eye-trackers use contrast to locate the centre of the pupil, in addition to infrared and near-infrared non-collimated light to create a corneal reflection (CR). The vector between these two features can be used to compute gaze intersection with a surface after a simple calibration for an individual.

Eye-tracking setups vary greatly. Some eye-trackers are head-mounted, some require the head to be stable (e.g., with a chin rest), and some function remotely and automatically to track the head during motion. Most use a sampling rate of at least 30 Hz. Although 50/60 Hz is most common, many modern video-based eye-trackers run at 240, 350 or even 1000/1250 Hz, which is needed in order to capture the detail of the very rapid eye movements during reading, or during studies of neurology.

Eye-trackers measure the rotation of the eye with respect to the measuring system. If the measuring system is head mounted, as with the EOG, then eye-in-head angles are measured. If the measuring system is table mounted, as with scleral search coils or table mounted camera (“remote”) systems, then gaze angles are measured. In many applications, the head position is fixed using a bite bar (e.g., San Agustin, Skovsgaard, Hansen, & Hansen, 2009), a forehead support or something similar, so that eye position and gaze are the same. In other cases, the head is free to move (e.g., Tobii Eye-Tracker), and head movement is measured with systems such as magnetic- or video- based head trackers.

Headmounted eye-trackers are fixed on top of the user’s head (e.g., Eyelink), and head position and direction are added to eye-in-head direction to determine gaze direction. Desktop systems (e.g., EasyGaze) are tetherless and capture eye movement remotely in front of the participant. These types use search coils, and head direction is subtracted from gaze direction to determine eye-in-head position.

In general, eye-trackers are more accurate and will require less calibration when the head remains fixated, allowing only the eyes to move. As such, remote desktop mountings with chin rest options may provide the most granular measures, but may be uncomfortable and un-naturalistic for wearers. In addition, headmounted eye-trackers allow for more movement, but can be obtrusive and timely to set up. A third kind of eye-tracker that is rapidly gaining popularity is the goggle style eye-tracker (e.g., Mobile). These eye-trackers are often wireless using Bluetooth technology, and are designed for eye-tracking in real-life environments such as sport research (e.g., Crews & Lutz, 2008).

3.3 Eye-Tracker Use

Eye-tracking data, specifically eye movements or scan paths, have been used retrospectively to analyze usability issues and human performance within the human - computer interaction domain (Jacob & Karn, 2003). Real-time eye-gaze data have been investigated as an input tool for interface interaction. For example, Hornof, Cavender, and Hoselton (2004) describe a system that enabled children with severe motor impairments to draw pictures by just moving their eyes. A similar eye-drawing open-source product is developed by EyeWriter (EyeWriter Initiative: New York, NY), whose website provides detailed instructions on how to create your own drawing tool using parts from a Playstation gaming system.

Another use of eye-tracking, and of particular use and interest to the current review, is real-time processing of a user's gaze to interpret user non-explicit cognitive behaviours for online interaction adaptation. For example, Sibert, Gokturk, and Lavine (2000) described a system that tracks the reader's eye movements and, using principles derived from reading research, aids the reader by pronouncing words that appear to be hard to recognize.

Bulling et al. (2008) propose that the EOG may be used as a novel measurement technique for wearable eye-tracking and recognition of user activity and attention in more mobile settings (Bulling et al., 2008, p. 1). With the EOG, electrodes are typically placed around the eye so that when the eye moves from the center position towards one electrode, this electrode "sees" the positive side of the retina and the opposite electrode "sees" the negative side of the retina. Consequently, a potential difference occurs between the electrodes. Assuming that the resting potential is constant, the recorded potential is a measure for the eye position. A major benefit of the EOG lies in the minimal amount of power and computation that is required for signal processing.

3.4 Results of Literature Search on Eye-Tracking Technologies

The literature search on this subject yielded information containing eye-tracking technology that either directly involved, or was considered useful for implementation into intelligent tutoring systems. *Table 4* presents a list of the references examined in this literature review, classified by type of eye-tracking device used (e.g., headmounted), and by product specific information.

Table 4. Eye-tracking technology literature search: Reference list

Style	Product	Reference
Head Mounted & Goggle	ASL 501/504	• Louwerse, Graesser, McNamara, & Lu (2008) • North et al. (2009)
	SR Research Eyelink II	• SR Research (2010) • Zotov et al. (2009) • Keillor et al. (2006/2007)
	EOG Goggles	• Bulling et al. (2008)
	Scene Monocular	• Arrington Research (2010)
	ASL Mobile Eye	• Applied Science Laboratories
	Déjà View	• Li & Parkhurst (2006)
	Eye Writer	• Eyewriter (2010)
Desktop	ASL Eyetrac 6	• Applied Science Laboratories
	Design Interactive Easy Gaze	• Design Interactive (2010)
	Tobii (all)	• Klingner, Kumar, & Hanrahan (2008) • Tobii (2010)
	SR Research Eyelink 1000	• SR Research (2010)
	Gaze Tracker	• San Agustin et al. (2009)
	LC Technology Easy Gaze	• Sibert et al. (2000)

In addition, a summary of the desired qualities for eye-tracking technologies are presented in Table 5. This table was based on a list of requirements designed to aid in the selection of the most appropriate product to implement, followed by recommendations and suggested uses for the implementation of the adaptive e-learning framework of the IEDD course, based on the literature reviewed. The technologies within the eye-tracking literature were evaluated based on the following criteria:

- COTS: Is this product currently available commercially, off-the-shelf?
- Unobtrusive: Is this product invasive, bulky, or in any way uncomfortable so that it may affect desire to wear. Also, is it difficult to setup and calibrate alone?
- Affordable: Is this product within the reasonable budget to spend?
- User Support: Does the product offer any form of technical support or training after initial purchase?
- Build Own: Does the product offer instructions on how to build it oneself?
- Leave for IEDD course: Can this product remain in Canadian Forces Base (CFB) Gagetown, New Brunswick for use by the IEDD course students when the project is completed?

Table 5. Summary of Eye-Tracker Requirements Checklist

Style	Product	COTS	Affordable	Unobtrusive	User Support	Build Own	Leave for IEDD Course
Head Mounted & Goggle	ASL 501/504 (Applied Science Laboratories: Bedford, MA)	yes	no	no	yes	no	no
	Eyelink II (SR Research: Kanata, Canada)	yes	no	no	yes	no	no
	EOG Goggles (Swiss Federal Institute of Technology: Zurich, Switzerland)	no	n/a	yes	no	no	no
	Scene Monocular (Arrington Research, Scottsdale, AZ)	yes	yes	yes	yes	no	no
	ASL Mobile Eye (Applied Science Laboratories: Bedford, MA)	yes	no	yes	yes	no	no
	Déjà View (openEyes: Ames, IA)	yes	yes	yes	no	yes	yes
	Eye Writer (EyeWriter Initiative: New York)	no	yes	yes	no	yes	yes
Desktop Eye-trackers	ASL Eyetrac 6 (Applied Science Laboratories: Bedford, MA)	yes	no	yes	yes	no	no
	Easy Gaze (Design Interactive: Oviedo, FL)	yes	yes	yes	yes	no	maybe
	Tobii (all) (Tobii Technology: Sweden)	yes	no	yes	yes	no	no
	Eyelink 1000 (SR Research: Kanata, Canada)	yes	no	yes	yes	no	no
	Gaze Tracker (ITU Gaze Group: Denmark)	yes	yes	yes	yes	yes	yes
	Easy Gaze (LC Technology, Clearwater, FL)	yes	No	Yes	No	No	no

3.5 Recommendations and Suggested Use

From the results of the eye-tracking requirements in the *Table 5* checklist, the recommended choice (highlighted in grey) from a high level perspective is some form of desktop, remote eye-tracker. Desktop eye-trackers are the least invasive, as there is nothing touching the user, and require no external setup aside from calibration. The goggle style eye-tracker is less invasive than the headmounted, eye-tracker although it still does partially obstruct the user's view.

The recommended eye-trackers based on the selected criteria for use with the IEDD course would be Design Interactive's **EasyGaze**, or the **Gaze tracker**. Both of these brands are desktop models, they are affordable, commercially available, offer support, have been used in research and can be left at the military base. The **Déjà View** is recommended as a third choice of eye-tracker for use in the course, as it appears to be purchasable, buildable, and minimally obtrusive. Nevertheless, it is possible that the requirements defined here will change depending on the upcoming budget and course requirements. If so, the following list outlines some general guidelines that should be considered when purchasing an eye-tracker:

- If a premium, research-supported product is desired, and the budget for eye-tracking technology is large, it is recommended to purchase a product from Tobii, Applied Science Laboratories, or SR Research. These brands offer premium products that are used extensively in peer-reviewed academic research, and offer extended support and training for their products. Also, it is likely that these eye-trackers could be re-used in the future for related projects.
 - o Alternatively, if DRDC Toronto is able to borrow the Eyelink II from SR Research, it is recommended that this product be used.
 - o A second alternative is to consider renting an eye-tracker for the duration of the project. This could be a more affordable option to allow use of a premium eye-tracker to calibrate the low-cost alternatives that will remain at the course.
- If the budget for eye-tracking technology is low, it is recommended that DRDC Toronto purchase a product from Easy Gaze, or build its own tracker using the open-source analysis software EasyGaze. This software is made by Design Interactive, and has already been purchased by the client, making it an obvious choice.
 - o As one main eye-tracker has already been purchased, it is suggested that DRDC Toronto purchase and build low cost eye-trackers to leave for the IEDD course, as it is unlikely that the EasyGaze would remain in CFB Galetown. In this case, the primary eye-tracker could be used to gather baseline data and calibrate the lower quality eye-trackers.
- If the ITS is to be on a PC or in a laptop-style environment, it is recommended that a desktop (e.g., EyeGazer) or webcam style eye-tracker be used, as headmounted eye-trackers are invasive and more difficult to set up. The trade-off when using a desktop or webcam style eye-tracker may have a less accurate pixel capture and re-calibration capability if the user is distracted. However, the intrusive, unwieldy headgear associated with headmounted eye-trackers may deter their use altogether.

- If the ITS will be used in a real life, or virtual immersive environment where the user is physically moving within that environment, a goggle style eye-tracker (e.g., Mobile Eye) is recommended, as these types of eye-trackers are built for indoor/outdoor lighting conditions, and allow the participant to move freely about in the environment.

Of note for upcoming technological implementations is that the chosen ITS eye-tracker will need to provide real-time x- and y- coordinate output of eye-position to determine what the user is actually looking at. Typically, in eye-tracking research, the eye-tracker produces heat maps of gaze patterns which are analyzed retrospectively by the researcher. However, for the ITS, the researcher's static knowledge of participant gaze is not sufficient. In this case, it is proposed that the data be analyzed in real time, which could potentially pose integration problems, and increase the overall complexity significantly.

To attempt to remedy this issue, some type of software developer's kit (SDK) will need to be acquired with whatever eye-tracker is used in order to feed the resulting x- and y- data into the corresponding ITS. The accessibility of the analysis software (i.e., open source of the architecture code) will determine whether the ITS will then have to interpret the meaning of the eye position, or if a pre-packaged analysis software could provide these data.

From a technical standpoint, it is possible that eye-tracking at this early stage, in fact may be too complex and time consuming to feasibly incorporate into a proof of concept project. Ultimately, it is strongly recommended that the actual ability and effort required to merge real-time eye-tracking data into an adaptive system be considered.

4 Cognitive Learning Styles

As the CF demonstrate their readiness for distance and e-based learning, it is imperative to understand the challenges that may accompany the technology and approaches used. According to DRDC Toronto, one of the most difficult activities for a distance education facilitator will be to provide the same or higher degree of responsiveness to the student as would a classroom facilitator, and to customize the learning experience to each student's individual learning style. One of the mechanisms to facilitate the learning experience is intelligent tutoring technology. To make the technology effective in a distance learning environment, student learning styles must be investigated prior to implementing any technology in order to facilitate the customization of each student's learning experience.

This section reviews relevant literature and technology related to learning styles in order to make recommendations and suggested use for implementation within an ITS for the IEDD course.

4.1 Introduction to Learning Styles

Research has shown that different students approach learning tasks and interact with learning environments in different ways. As such, each student develops a specific set of learning behaviours to which he or she becomes accustomed. Such viewpoints have led to suggestions of tailoring educational interactions to students' cognitive or learning styles in the context of computer and web-based learning environments (for a review, see Pronovost, Roberts & Banbury, 2008). The flexibility offered by such environments should enhance learning, allowing students to develop personal navigation patterns and interaction behaviours that reflect on their own cognitive characteristics.

Cognitive and learning styles refer to roughly overlapping yet distinct theoretical constructs employed by a number of diverse research fields related to the topic of learning; such as cognitive psychology, educational psychology, personality psychology, psychoanalysis, neuropsychology, and cognitive and behavioural neuroscience.

Cognitive style can be defined as “an individual's characteristic and consistent approach to organizing and processing information” (Tennant, 1988). From this perspective, cognitive style is considered to be a central and unchanging part of the individual's personal and psychological makeup or “a fixed characteristic of an individual” (Riding, 1996). For example, Anderson (2004) defines cognitive learning styles as:

“... the information processing habits of an individual. Unlike individual differences in abilities, cognition describes a person's typical mode of thinking, perceiving, remembering, or problem solving. Cognitive style is usually described as a personality dimension which influences attitudes, values, and social interaction. For example, ask yourself how you process experiences and knowledge and how you organize and retain information. Do you need to visualize the task before starting? Do you approach learning and teaching sequentially or randomly? Do you work quickly or deliberately? These are examples of cognitive learning style characteristics. The biological basis for cognitive learning styles is grounded in brain theory.” (Anderson, 2004).

It should be noted that the terms cognitive style and cognitive learning style are often used interchangeably in the literature, and refer to the same construct. Importantly, cognitive style (or cognitive learning style) differs from learning style as the latter can be considered to vary over time and space (Valley, 1997). It is important to note that in this report, we use the term “Learning Styles” to refer to all cognitive and learning styles.

4.2 Synthesis of Cognitive Learning Styles Knowledge

Recently, DRDC Toronto started a survey and synthesized the body of knowledge on student learning styles and intelligent tutoring technology. This review was then used to develop recommendations on how to integrate knowledge of the user’s learning style into adaptive learning and intelligent tutoring technologies so as to facilitate a positive learning experience (Hou, Sobieraj, Pronovost, Roberts, & Banbury, 2010). In this investigation, 13 of the most influential cognitive and learning styles were critiqued as based on the comprehensive in-depth review by Coffield, Moseley, Hall, and Ecclestone (2004a, 2004b) of 71 cognitive and learning styles. To date, the review of Coffield et al. is the single and most impartial review of the literature on cognition, learning, and pedagogy.

The learning styles reviewed in the DRDC report were based on the criteria of being widely quoted and central to the field as a whole, having a basis in explicit theory, having publications that were representative of the literature and the total range of models available, the theory having been proven to be productive (i.e., leading to further research by others), and the instruments/questionnaires/inventory having been widely used by practitioners, teachers, tutors or managers. *Table 6* is an example of some of the 13 key learning styles that were examined in the report by Hou et al., (2010), in addition to their respective strengths and weaknesses as based on the reviews by Coffield et al.

Table 6. Excerpt of reviewed learning styles from Hou et al. (2010)

Learning Style	Advantages	Weaknesses
Allinson and Hayes' Cognitive Styles Index (CSI)	• Best evidence for reliability and validity. • The constructs of analysis and intuition are relevant to decision making and work performance in many contexts, although the pedagogical implications of the model have not been fully explored. • The CSI is a suitable tool for researching and reflecting on teaching and learning, especially if treated as a measure of two factors rather than one. • Matched styles are often effective in mentoring relationships	• The proposed single dimension is very broad and made up of diverse, loosely associated characteristics. • Despite the claims of its authors, the CSI has been shown to measure two related, albeit multi-faceted, constructs. • The popularized stereotype of left- and right-brained-ness creates an unhelpful image of people going through life with half of their brains inactive. . • Intuition and analysis are not opposite, mutually exclusive features
Entwistle's Approaches of Study Skills Inventory for Students (ASSIST)	• Model aims to encompass approaches to learning, study strategies, intellectual development skills and attitudes in higher education. • Considerable literature validating the model and theoretical background. • Teachers and learners can share ideas about effective and ineffective strategies for learning	• Complexity of the developing model and instruments is not easy for non-specialists to access. • Danger of categorizing or stereotyping learners' characteristics if theory and model not known in depth. • There is a large gap between using the instrument and transforming the pedagogic environment
Kolb's Learning Style Inventory (LSI)	• Fairly detailed history of revisions and reviews. • Theory based on explicit assumptions	• Contradictory and inconclusive findings. • Issues on reliability and validity. • Concept of learning cycles controversial
Myers-Briggs' Type Indicator (MBTI)	• Face validity is uncontroversial, limited evidence of positive pedagogical implications of matching learning style between learners and educators	• Unclear implications for pedagogy, not a performance predictor. • Construct validity is contested

The DRDC report (Hou et al., 2010) concluded that there was a lack of substantial evidence to select any one theory, arguing that the review of Coffield et al of cognitive and learning styles was not definitive, nor was it conclusive about most of the theories, models, and psychometric tools reviewed as a function of the lack of independent validation data. On the positive side, Coffield et al. acknowledge that pragmatically-oriented concerns, such as Kolb's, Entwistle's, and Vermunt's interest in changing the whole teaching - learning environment, beyond considerations to individual differences in learning styles, should be pursued for the betterment of education and

pedagogy. Conversely, other opportunities for the implementation of cognitive and learning style models (e.g., career counselling and personnel selection) are not recommended as based on the observation that the psychometric tools available remain largely unvalidated. Furthermore, the concepts of style matching, or deliberate mismatching of learning styles between students working in groups or between students and tutors, are consistently *unsupported* by research. While it is intuitively appealing, no evidence suggests an increase in performance.

The most vehement criticism by Coffield et al relates to the assertion that learning styles ought to be significant to a certain degree that *matters* for education and pedagogy (i.e., validation data show meaningful effect sizes). However, very few reviewers have actually measured effect sizes, whether by using Pearson's R correlation (when the data are continuous or binary) and its accompanying coefficient of determination (R^2 , a measure of the proportion of variance shared by the two variables), d (in the context of a t-test on means) (Cohen, 1988) or eta squared (η^2 , the proportion of variance explained in an analysis of variance). Those studies that have done so show disappointing results.

In summary, the criticisms of learning styles compiled by Coffield et al. relate to:

- The presence of some theoretical incoherencies and conceptual confusions in the constructs and factorial designs of such constructs;
- Practical issues related to learning styles such as labeling and stereotyping, as well as some vested interests from the authors;
- The variable quality of learning style models;
- Widespread psychometric weaknesses derived from the learning style models;
- The unwarranted faith placed in simple inventories;
- No clear implications for pedagogy; and,
- The lack of communication between different research perspectives on pedagogy.

In response to the inconclusive findings of Coffield et al., this review was extended in an attempt to locate new learning styles that were not reviewed by them, or to provide more concrete evidence for the reliability and validity of the styles that had already been covered. The search yielded the Index of Learning Styles (ILS; Felder & Silverman, 1988; Felder & Solomon, 2006). The ILS was also briefly touched upon for use in intelligent tutoring systems by Banbury et al. (2009); however, the single reference provided was insufficient to justify the ILS's sole use in the current recommendations. As a result, this review has included updated and detailed support for the use of the ILS within the proposed ITS for the IEDD course.

4.3 Detailed Review of Index of Learning Styles (ILS)

This sub-section provides an overview of the Felder-Solomon Index of Learning Styles. In addition, this section introduces an adaptive learning aid (LOCATETM), which is a software that was developed within DRDC to aid in the design of workspaces using learning styles. Although this learning aid does not specifically use the ILS, the learning style dimensions assessed by LOCATETM do appear to be very similar to those assessed by the ILS. As such, LOCATETM was

deemed important to include in this section as it is an internally designed application which may be of interest to distance education and e-learning in the CF.

4.3.1 Overview and design of model

Felder and Solomon's Index of Learning Styles (Felder & Solomon, 2006), is an instrument used to assess preferences on four dimensions of a learning style model that was formulated by Felder and Silverman (1988). The ILS can be classified as resting within the category of learning styles having flexible traits (Coffield et al., 2004a; 2004b). It was developed based on the belief that the primary goal of a learning style model should be to provide guidance to instructors on how to develop a balanced teaching method that addresses the needs of students with diverse learning style preferences (Felder, Litzinger, Lee, & Wise, 2005).

The ILS consists of 44 items, broken down into four scales of 11 questions, with each scale corresponding to one of the four dimensions of the learning style model (Felder & Silverman, 1988). To note, each of the four dimensions contains a set of two opposite categories. The idea behind these opposite categories is that everyone uses all of them at different times, but with varying degrees of preference.

The four dimensions in the ILS are:

- The Active/Reflective Dimension: How do you prefer to process information?
 - Active learners prefer to process information by talking about it and trying it out (e.g., they prefer active student participation in groups).
 - Reflective learners prefer to think about information before acting (e.g., they prefer passive student participation by themselves or with one familiar partner).
- The Sensing/Intuitive Dimension: How do you prefer to take in information?
 - Sensing learners prefer to take in information that is concrete and practical.
 - Intuitive learners prefer to take in information that is abstract, and more conceptual in nature.
- The Visual/Verbal Dimension: How do you prefer information to be presented?
 - Visual learners prefer visual presentations of material: diagrams, charts, graphs, pictures.
 - Verbal learners prefer explanations with words, in the form of both written and spoken presentations.
- The Sequential/Global Dimension: How do you prefer to organize information?
 - Sequential learners prefer to organize information in a linear, orderly and systematic fashion.

- o Global learners prefer to organize information more holistically and in a seemingly scattered and disorganised manner.

As previously mentioned, each dimension consists of two categories of opposite preferences, and each category has a score ranging from 1 to 11. In the ILS, students complete a sentence by selecting one of two response options representing opposite ends of one of the learning styles scales. Scores ranging from 1 to 3 indicate that the student is well balanced between the two categories of a particular learning styles dimension. For scores between 5 and 7, a moderate preference is indicated, which means favouritism for one of the two categories. Scores between 9 and 11 indicate a very strong preference, meaning that the student will have difficulty with learning in an environment that does not support that preference.

4.3.2 Reliability and validity

Felder and Spurlin (2005) conducted the first comprehensive examination of the ILS and assessed the reliability and validity of 21 external studies using the instrument. These analyses were conducted by examining Pearson correlation coefficients. To note, the correlation coefficient is a statistic that represents how closely two variables co-vary, or the extent to which changes in one variable are associated with changes in the other variable. Importantly, the correlation coefficient indicates the strength and direction of the relationship between two variables. It can vary from -1 (perfect negative correlation) through 0 (no correlation) to +1 (perfect positive correlation).

The Felder and Spurlin review indicated that the test - rest reliability of the ILS was acceptable as it fell in the correlation ranges of .73 to .87 after 4 weeks, and .56 to .77 after 10 weeks. All correlation coefficients were significant at the 0.05 level or better thus indicating that participant responses to the ILS did not change greatly over time. The internal consistency of the four dimensions ranged from .51 to .62 for Active/Reflective, from .65 to .76 for Sensing/Intuitive, from .56 to .69 for Visual/Verbal, and from .41 to .54 for Sequential/Global. These reliability coefficients all meet the minimal standard of .50 that was suggested by Tuckman (1999) for preference and attitude assessments. They also suggest that the test items for each subscale were effectively tapping into their target dimension.

A factor analysis was conducted with the ILS and revealed that the Active/Reflective, Sensing/Intuitive, and Visual/Verbal dimensions are orthogonal. The Sequential/Global and Sensing/Intuitive dimensions were found to be associated, and, thus, assessing both dimensions may lead to redundancy. Pearson correlation coefficients relating preferences on the different dimensions of the ILS in four studies were consistently .2 or less except for Sensing/Intuitive and Sequential/Global dimensions (which ranged from .32 to .48). Again, this suggests that the Sensing/Intuitive and Sequential/Global dimensions may be assessing many of the same preferences.

4.3.3 Implications for pedagogy and evidence of pedagogical impact

Unlike many of the other learning styles theorists, Felder and Solomon are not proponents of directly matching educational strategies and pedagogical tools to individual learning styles. Instead, they assert that most students learn differently than their instructors, and other students. Thus, it becomes impossible for an instructor to simultaneously address the learning needs of all

students. Additionally, an instructor's preferred method of teaching may be influenced by his/her own learning style preferences. Instructors must be mindful of these personal biases in addition to being aware of the diverse learning needs of their students. The most effective instructors will be those who can present material using the widest array of teaching methods, thereby catering to as many learning style preferences as possible.

Several researchers have cited positive student outcomes following the introduction of multifaceted pedagogical tools and methods that cater to students with diverse learning styles. Felder (1995) investigated the performance of chemical engineering students who were exposed to novel instructional methods (e.g., use of realistic examples, field experiences, guest speakers, etc.) or more traditional instructional methods (e.g., long lectures, homework assignments, etc.). It is important to note that the novel instructional methods addressed a wider array of learning style needs than did traditional instructional methods, which cater to students with verbal and sequential learning style needs (i.e., long verbal lectures and homework assignments requiring step by step problem solving). Felder documented that students in the novel instruction group exhibited superior performance as compared to students receiving traditional instruction. For example, these students showed greater proficiency in generating creative solutions to problems, enhanced teamwork skills, and an increased likelihood of attending graduate school.

In a related study, Tripp and Moore (2007) introduced pre-service elementary school teachers to the ILS and instructed them on how knowledge of learning styles can be incorporated into teaching strategies. The pre-service teachers reported that after gaining greater awareness of learning styles, they felt more sensitive to the needs of their students, and, in turn, this enabled them to prepare better lesson plans. This suggests that instructors should also be assessed with the ILS, so that they can compare their own styles with those of their students, which in turn will lead to positive pedagogical outcomes.

4.3.4 Applications

The ILS is intended for use with adults, especially higher education students and their instructors. It is important to remember that proponents of the ILS do not advocate the necessity of matching student and instructor learning styles, as doing so would be quite arduous due to the high number of possible learning style combinations. Instead, proponents advocate the use of teaching methods that present material in a wide variety of ways, thereby catering to diverse learning style preferences. In turn this leads to positive performance outcomes for students and heightened feelings of effectiveness for instructors (Felder, 1995; Tripp & Moore, 2007).

There are no apparent suggestions for use of the ILS in the workplace. However, several e-learning applications have been put forth. Kim, Kim, Cho, and Park (2005) designed an intelligent learning environment where the individual's learning style preferences were diagnosed through their activity patterns on a webpage. Subsequently, individual user interfaces were customized in an adaptive manner to accommodate these preferences. In this way, the e-learning program was able to present learning content in a way that appealed to all learning styles. Similarly, Graf and Kinshuk (2007) went one step further by assessing the effectiveness of adaptive e-learning systems. Students were randomly assigned to one of three groups:

- The “matched” group was presented with a course that matched their learning style;
- The “mismatched” group was presented with a course that mismatched their learning style; and
- The “standard” group was presented with a course in a sequence that was independent of their learning style. The researchers found that students from the “matched” group spent less time in the course but achieved on average the same scores as students in the other groups.

The authors suggested that this quicker completion time among students in the “matched” group is an indication of their heightened satisfaction with the course as due to an increased ease of interaction with the e-learning system.

4.3.5 Application of the ILS at DRDC: LOCATE™

LOCATE™ (Edwards, 2005; Scott & Edwards, 2006; Edwards & Scott, 2007) represents an application of the ILS within the specific context of DRDC’s adaptive learning requirements. It is a software tool that aids in the design of workspaces using learning styles. Even though it does not specifically use the ILS, the learning style dimensions that it does assess are similar to those assessed by the ILS.

LOCATE™ supports the design, analysis, and optimization of workspace layouts based on the type and nature of the work to be conducted. One key aspect of LOCATE™ is an adaptive help system, which plays a key role in DRDC Toronto’s ongoing efforts to develop and refine adaptive learning technologies. LOCATE™’s user model contains information about the user’s knowledge, preferences, abilities, and learning style, which enables the software to make informed decisions about the style of help that it offers to its user.

To assess learning style, LOCATE™ asks users to answer a set of questions, as based on the Cognitive Style Questionnaire (CSQ) that was developed by Edwards (2005). According to the CSQ, learning styles fall along a Verbal, Imagery, and Kinaesthetic tri-mension and a Holistic and Analytic dimension (see *Figure 1*).

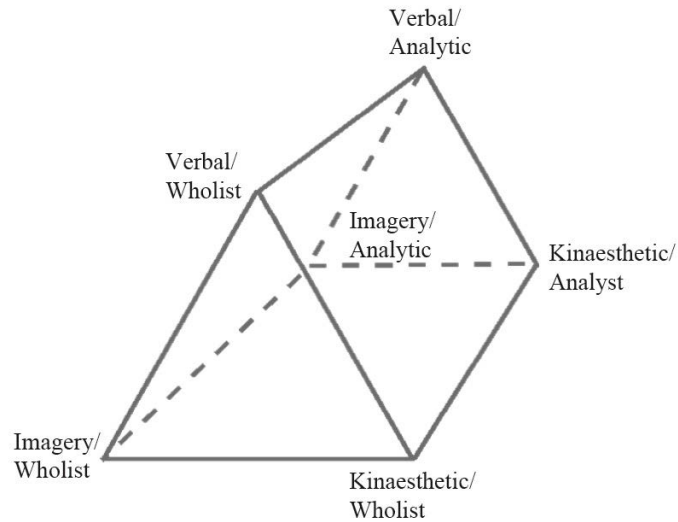


Figure 1. Cognitive style modelled as a triangular solid

It is important to note that the learning style preferences assessed by the CSQ are very similar to those assessed by the ILS:

- Verbal/Analytic: Textual descriptions of how tasks are performed; Verbal/Wholist: Textual descriptions of task performance, including contextual information. (Similar to ILS's **Visual/Verbal** dimension);
- Imagery/Analytic: Animated demonstrations in which the software shows exactly how a task is performed, directly in LOCATE™'s interface; Imagery/Wholist: Graphical instructions, where the steps in carrying out a task are illustrated with a sequence of still images and contextual information on the feature is available. (Similar to ILS's **Global/Sequential** dimension);
- Kinaesthetic/Analytic: Practice sessions in which users can try out a feature in LOCATE™ as they learn about it; Kinaesthetic/Wholist: Practices session in which users can try out LOCATE™'s features, with additional information on the context in which those features are used. (Similar to ILS's **Sensing/Intuitive/** and **Active/Reflective** dimensions).

The information that is derived from user responses to the CSQ is stored in the user model. As help is requested by the user, the help material is provided in a format that is most supportive of the user's learning style. Importantly, LOCATE™ continuously adapts the format of the help system to the user's learning preferences by tracking the user's behaviour as he or she selects alternatives.

Importantly, the current work of Edwards (2005), and Edwards and Scott (2007) involving LOCATE™ and learning space in the design of workspace layouts and user "help" functions is still in need of validation and further testing. One recommendation that can be taken from the work on LOCATE™ is the integration of learning styles into the user's help menu when designing adaptive distance education and e-learning technologies for use with the CF. In this way, the learning styles of the user would be assessed at the start of the learning session, and whenever the user would subsequently request help from the system, options would be provided in the user's preferred style of help (e.g., visual, text, video clips, interactive, etc.). In addition, options could be provided to the user to select help in a form other than the system's recommended style, which would allow for the system to adapt to the user's preferred style of help.

4.3.6 Overall assessment

A review of the literature suggests that the immediate advantage of the ILS is that it encompasses the advantages of several of the previously reviewed learning styles, and also has recent data to support its reliability and validity (Felder & Spurlin, 2005; Palapu, 2007). However, a factor analysis did reveal low orthogonality between the Sequential/Global and Sensing/Intuitive dimensions of the ILS, thereby suggesting that there may be some redundancy between these two dimensions. In terms of pedagogy, researchers have documented that the use of the ILS does lead to positive pedagogical outcomes, with heightened performance among students and enhanced self-reported sensitivity to student needs among instructors (e.g., Tripp & Moore, 2007). Importantly, the ILS has also been incorporated into several e-learning programs (e.g., Graf & Kinshuk, 2007), and has led to positive student outcomes. In turn, this suggests that the incorporation of the ILS into computer-based learning and distance education may lead to favourable learning outcomes. It remains to be seen whether or not the ILS can be applied in business contexts. Finally, as based on favourable outcomes following DRDC's design of a learning aid called LOCATE™, which is based upon the ILS, it is recommended that the ILS model should be used to identify the learning styles of CF learners undergoing computer-based training in a distance educational context in order to improve learning effectiveness.

4.4 Recommendations and Suggested Use

- It is recommended that the ILS (Felder & Solomon, 2006) be used as a tool to identify the learning styles of CF learners undergoing computer-based training in a distance educational context in order to customize their learning experience.
- A baseline of learning styles should be assessed using the ILS online questionnaire administered to capture the initial values used to represent the learner's style.

- Baseline ILS styles should be compared against the style of current IEDD course teaching/presentation styles to see if the areas where people are failing are indeed those which show a mismatch between learning and teaching style, and/or presentation of information.
- Given the low orthogonality between the Sequential/Global and Sensing/Intuitive dimensions of the ILS (Felder & Spurlin, 2005), and the increased effort required to build content in multiple learning style formats, it is recommended that focus should be given to the design of the ITS's course content to correspond to only three dimensions of the ILS, which will reduce redundancy.
- It is suggested as in Tripp and Moore (2007), that IEDD course instructors also be assessed with the ILS, and allowed to compare their own styles with those of their students. The goal is that teaching can be improved when teaching styles are better matched with learning styles. This suggestion allows for students of the IEDD course to benefit from an integrated ILS within the entire course content beyond the online components.
- Although the current work of Edwards and Scott (2005, 2007) involving LOCATE™ and learning styles in the design of workspace layouts and user “help” functions is still in need of validation and further testing, it is recommended to re-visit the underlying architectures and processes involved in the building and design of the LOCATE™ program.
 - It is currently beyond the scope of this report to make recommendations about computational architectures and other programming strategies, however, this reference has been noted as having potential value to the current project, and will be considered in greater detail in upcoming projects relating to the design of the ITS.
 - Furthermore, it should be noted that the learning styles implemented in LOCATE™ parallel those of this report's suggested ILS. For instance, Edwards (2005) distinguishes among visual, textual, holistic (global), active and reflective type domains. As such, it is recommended to check for more recent references from these authors when the current program is closer to the actual design integration.
- One recommendation that can be taken from the work on LOCATE™, however, is the use of learning styles to be integrated into the user's help menu. The program created a new resource called “how to” help, designed to provide procedural help in carrying out tasks. When a user requests help from the system, options are provided to select help in a form other than the system's recommended style, which allows for the system to adapt to the preferred style of help (e.g., visual, text, video clips, interactive, etc.)
 - It is recommended that a similar help strategy for the IEDD course ITS be adapted; one suggestion is to incorporate an area where operators can practice and “try-things out”, or watch demonstrations of interviews done correctly and incorrectly.
 - Also, learning styles could be incorporated into the hints given by the tutor.
 - A potential issue to note is that the creation of multiple learning style content extensively increases the complexity and work expenditure of the programmers

involved. Therefore, it is advisable to begin by implementing fewer learning styles, and building onwards following a proof of concept.

5 Psychophysiological Measures

Psychophysiology deals with the interactions between the mind and body by recording how the body is functioning and relating these functions to recorded behaviour. The field is based on the premise that changes in the body are related to changes in behaviour, affect and motivational states (Blanchard, Calhoun, & Frasson, 2007).

According to Conati and Merten (2007), psychophysiological techniques makes it possible to identify differences in human brain processing that correspond to differences in learning styles and capabilities. These techniques also have the potential to reveal the learners' cognitive state. Psychophysiological recording techniques are generally non-invasive, that is, they record from the body's surface and nothing enters the body of the person that is being recorded.

Although there are numerous ways to categorize these measures (for examples, see Karamouzis, 2006), in this section, psychophysiological technologies have been categorized in terms of the type of measurement they provide (e.g., mental and physical workload, stress, attention, etc.).

There are multiple ways to measure psychophysiological responses. and even more technologies available to do so. However, not all available technologies and measurements are applicable for the current project. As such, the current review focuses on the most relevant measures that fit the needs of the IEDD operator course. For instance, as the course will be designed for individual PC use, it did not make sense to include references on measures of physical arousal such as electromyography. The electromyograph (EMG) measures the electrical energy present during muscle activation.

This section describes the relevant psychophysiological measures considered for this report. Again, the section ends with a brief overview of the reference material, followed by recommendations and suggested use.

5.1 Mental Workload

A commonly researched variable of performance is the assessment of mental workload. Mental workload is a broad concept that refers to the amount of processing capacity that is expended during task performance (Eggemeier, 1988). At its core, mental workload refers to the difference between the processing resources available to the operator and the resource demands required by the task (Sanders & McCormick, 1993). The term “workload” delineates the difference between capacities of the human information processing system that are expected to satisfy performance expectations, and the capacity available for actual performance (Gopher & Donchin, 1986).

Mental workload alone only describes a series of measures of physiological indices produced by the human body. Common measures of mental workload are the electroencephalogram (EEG), heart rate variability (HRV- a measure involving the electrocardiogram [ECG]), and galvanic skin response (GSR) either alone, or preferably in combination with one another. These type of measures are useful metrics of mental workload, as they provide immediate feedback of mental processing of the task at hand (Byrne & Parasuraman, 1996; Gale & Christie, 1987; Kramer,

1991; Parasuraman, 1990). As such, both type of measurements have unique properties that make them ideal for adaptive automation.

Despite the many other available metrics that have been used to measure workload, this report focuses on the three aforementioned metrics due to their widespread use and accessibility within academic research, as well as the feasible constraints on data integration imposed by them in consideration of their implementation into the proposed ITS. The following sub-sections describe EEG, HRV (and ECG) and GSR in order to make recommendations and suggested uses for the IEDD course ITS.

5.2 Electroencephalogram (EEG)

The EEG records the electrical activity along the scalp produced by the firing of neurons within the brain (Niedermeyer & Silva, 1999). The EEG is a method of capturing and measuring brain waves to indicate how the brain functions over time. In the conventional scalp EEG, the recording is obtained by placing electrodes on the scalp with a conductive gel or paste, usually after preparing the scalp area by light abrasion to reduce impedance due to the skin cells (Abou-Khalil & Musilus, 2006). Many systems typically use electrodes, each of which is attached to an individual wire. Some systems use caps or nets into which electrodes are embedded; this is particularly common when high-density arrays of electrodes are needed.

The output from an EEG system is recorded as a graph of brainwaves on a time scale, and simply reveals rough brainwave frequency and amplitude. Measuring event related potentials (ERPs) involves correlating the EEG brainwave response with a stimulus (event) and averaging the result of dozens to thousands of stimulus expositions together to get a clear picture of what electrical activity took place upon presentation of that specific stimulus (Karamouzis, 2006).

5.3 Electrocardiogram (ECG)

The ECG records, non-invasively, the electrical activity of the heart over time typically by way of skin electrodes. The heart emits the highest electrical activity of all the body's organs, providing robust physiological data about the user's load levels that might be more difficult to detect via the EEG alone. While the EEG provides information on mental load, the ECG affords a robust identification of motor-related activity (Chen & Vertegaal, 2004). According to Prinzel, Freeman, Scerbo, Mikulka, and Pope (2003), cardiovascular activity is the most commonly used index of cognitive workload as it is relatively unobtrusive, reliable, easy to use and interpret (Fahrenberg & Wientjes, 2000), and appears to be readily accepted by those in an operational environment.

The ECG has been used to assess a user's emotional state at a given point in time, which relates to mental workload outputs such as anger or frustration. For example, McCraty, Atkinson, Tiller, Rein, and Watkins (1995) demonstrated that specific emotions could be distinguished based upon the power spectrum of the ECG. The other main usage of the ECG is to further calculate one's HRV. According to McCraty et al., in cases of stress, there is a tendency for increased heart-rate variability in the lower frequency ranges. McCraty et al. (1995) claim that stress measures provided by ECG low frequency components correlate well with the mental load of users during complex visual tasks as measured by the National Aeronautics and Space Administration Task Load Index (NASA TLX) - a subjective workload assessment tool.

5.4 Heart Rate Variability (HRV)

The HRV is derived from the ECG and measures naturally occurring, beat-to-beat changes in heart rate (McCraty, 2003). A synthesis of publications under McCraty at the Institute of HeartMath Research Centre (Boulder Creek, CA) suggests that mental and emotional states directly affect cardiovascular activity, and therefore the HRV. While the rhythmic beating of the heart at rest was once believed to be monotonously regular, it is now known that the rhythm of a healthy heart under resting conditions is actually irregular. These moment-to-moment variations in heart rate are easily overlooked when average heart rate is calculated.

Systems-oriented models propose that HRV is an important indicator of both physiological resiliency and behavioural flexibility, reflecting the individual's capacity to adapt effectively to stress and environmental demands (McCraty, 2009). In a healthy individual, the heart rate estimated at any given time represents the net effect of the parasympathetic nerves, which slow heart rate, and the sympathetic nerves, which accelerate it (Tiller, McCraty, & Atkinson, 1996). These changes are influenced by emotions, thoughts and physical exercise (McCraty et al., 1995). One's changing heart rhythms affect not only the heart but also the brain's ability to process information in the processes of decision-making, problem-solving and creativity. Thus, the study of HRV is a powerful, objective and non-invasive tool used to explore the dynamic interactions between physiological, mental, emotional and behavioural processes.

HRV generally increases and decreases as a function of cognitive workload. Prinzel et al. (2003) reviewed previous HR (heart rate)/HRV literature and concluded that the research suggests that the "mid-band" HRV can accurately measure changes in mental workload, while retaining the properties of diagnosticity, sensitivity, reliability, and ease of use. Furthermore, Chen and Vertegaal (2004) were able to demonstrate that HRV and the EEG were directly related, classifying active or passive participation in a task. Therefore, HRV has the potential, like the EEG to be used as a physiological "trigger" for invoking adaptive automation.

5.5 Galvanic Skin Response (GSR)

The GSR, also known as the electrodermal response (EDR), psychogalvanic reflex (PGR), or skin conductance response (SCR), can be used as an indicator of one's level of excitement or relaxation. Electro-dermal activity measures have been found to indicate mental effort, levels of arousal and vigilance and may also respond to affective stimuli (e.g., Chen & Vertegaal, 2004). When one is mentally, emotionally, or physically aroused, a response is triggered in the skin. During excitation, sweat glands in the skin fill with salty sweat which acts as a weak electrolyte and conductor.

Due to the response of the skin and muscle tissue to external and internal stimuli, the resistance can vary. Higher arousal (such as occurs with increased involvement) will almost instantaneously (0.2 - 0.5 seconds) cause a fall in skin resistance; reduced arousal (such as occurs with withdrawal) will cause a rise in skin resistance (McCleary, 1950).

When correctly calibrated, the GSR can measure these subtle differences. There is a relationship between sympathetic activity and emotional arousal, although one cannot identify the specific emotion being elicited. As such, it is important to interpret any GSR output with caution, and this

output should be used in multimodal combination along with other psychophysiological measures if one's goal is to make workload inferences (Shepherd, 2009).

As described by Shepherd (2009), stimuli such as words perceived by the human auditory system carry emotional charges that influence one's arousal level, and affect the skin's conductivity. Shepherd goes on to assert that the hands, representing a large proportion of sensitive nerve endings linking to the sensory-motor strip of the cortex, make hand-held electrodes an ideal and non-invasive point of contact for research.

A psycho-galvanometer measures the resistance of the skin to the passage of a very small electric current. The two paths for current are along the surface of the skin and through the body, and the device measures electrical resistance between two points (McCleary, 1950). The current sent causes the Tarchanoff Response – this refers to a change in direct current (DC) potential across neurons of the autonomic nervous system connected to the sensory-motor strip of the cortex (Shepherd, 2009). This change is related to the level of cortical arousal (Ellaway, Huppuswamy, Nicotra & Mathias, 2010). As arousal increases, the "fight or flight" stress response of the autonomic nervous system comes into action, and adrenaline causes increased sweating amongst many other phenomena. However, the speed of the sweating response is nowhere near as instantaneous or accurate as the Tarchanoff Response.

Classic technologies used for measuring the GSR include strapping electrodes to the index and middle finger, while more recent research, such as that of Handwave (Strauss, Reynolds, & Picard, 2005) and Brainquiry ("Neurofeedback equipment - Wireless Brainquiry PET EEG and ActivEEG"), has explored tetherless and wireless approaches. Also, the GSR Temp 2X (Thought Technology Ltd: Montreal, Canada) offers a model where the user only has to place his or her fingers lightly on top of the device, versus being strapped to it. Nevertheless, the device is still attached to computer.

5.6 Results of Literature Search on Psychophysiological Measures

The literature search on psychophysiological measures yielded literature containing psychophysiological measures that either directly involved, or was considered useful for implementation into, intelligent tutoring systems. *Table 7* presents a list of the references examined in this literature review, classified by type of psychophysiological measure (i.e., EEG, HRV, or GSR).

Table 7. Psychophysiological measures literature search: Reference list

Type	References
EEG	• Thought Technology Ltd. (2005) • B-Alert • St. John, Kobus, & Morrison (2004) • Chen, & Vertegaal (2004) • Blanchard et al. (2007)
HRV	• McCraty (2002a, 2002b, 2003, 2009) • Tiller, McCraty, & Atkinson (1996) • McCraty et al. (1995) • Biocomtech • emWave
GSR	• Mandryk, Inkpen, & Calvert (2006) • Or & Duffy (2007) • GSR Temp 2X (Thought Technology Ltd., 2010)

A summary of desired qualities for the psychophysiological measures is presented in *Table 8*. The recommendations and suggested use of psychophysiological measures for adaptive learning were based on the following requirements:

- COTS: Is this product currently available commercially, off-the-shelf?
- Affordable: Is this product within the reasonable budget to spend?
- Unobtrusive: Is this product invasive, bulky, or in any way uncomfortable so that it may affect desire to wear? Also, is it difficult to setup and calibrate alone?
- User Support: Does the product offer any form of technical support or training after initial purchase?
- Build Own: Does the product offer instructions on how to build it oneself?
- Leave for IEDD course: Can this product remain in CFB Gagetown for use by the IEDD course students when the project is completed?

Table 8. Summary of Requirements Checklist for Psychophysiological Measures

Style	Product	COTS	Affordable	Unobtrusive	User Support	Build Own	Leave for IEDD Course
EEG	Flexcomp Infiniti & Biograph (Thought Technology Ltd: Montreal, Canada),	yes	maybe	No	yes	no	No
	B-Alert (Advanced Brain Monitoring Inc: Carlsbad, CA)	yes	?	No	yes	no	No
HRV	Heart Tracker 3.0 (Biocom Technologies, Poulsbo, WA)	yes	yes	yes	yes	no	yes
	Biocom HRM (Biocom Technologies, Poulsbo, WA)	yes	no	yes	yes	no	yes
	EmWave (HeartMath: Boulder Creek, CA)	yes	yes	yes	yes	no	yes
	HRV Live! (Biocom Technologies, Poulsbo, WA)	yes	yes	Yes	yes	No	maybe
	Heart Wizard (Advanced Wellness Solutions: Poulsbo, WA)	yes	yes	yes	yes	no	Yes
GSR	HandWave (Strauss, Reynolds, & Picard, 2005) (Massachusetts Institute of Technology: Cambridge, MA)	no	yes	yes	yes	yes	yes
	Mikron Scan (temperature) (Or & Duffy, 2007) (Mikron Instruments: San Marcos, CA)	yes	yes	yes	yes	no	yes
	Brainquiry (Brainquiry Diagnostics: New York, NY)	yes	no	yes	yes	no	no
	GSR Temp 2X (Thought Technology Ltd: Montreal, Canada)	Yes	Yes	Yes	yes	no	yes

5.7 Recommendations and Suggested Use

Given the results of the requirements checklist in *Table 8*, the **HRV Live!** and **GSR Temp 2X** are two possible products producing indices of workload that are recommended for purchase within the context of the IEDD course. These were chosen above all other products and types of measures for the following reasons:

First, at this time, the technology supporting the EEG is not affordable or unobtrusive enough to justify its inclusion in the ITS. The mechanisms underlying the capture of the EEG require a multitude of gelled electrodes to be placed carefully on the skull. This feat would be extremely difficult and cumbersome for students to set up on their own, and as such, this would defeat the purpose of having a self-sufficient tutor.

The reviewed products for HRV differ primarily by price and their analysis capabilities. Heart Tracker, Heart Wizard, HRV Live! and emWave use either ear or finger clips, and the Biocom HRM and HRV Live! are also available wirelessly with Bluetooth (Bluetooth SIG: Kirkland, WA). For PC use, all five can be considered equally non-invasive. In terms of price, EmWave is the most affordable at under \$50 per unit, while at the top of the price scale, the Biocom HRM and HRV Live! cost approximately \$2,000 each. Overall, the least expensive products may be ideal to leave for the course if multiple sessions are required. In addition, when one considers the less-than-sturdy design of these small electronic products, and that as a result, they may need to be replaced quite often, this actually increases the current, relatively-low calculated cost of the EmWave.

Akin to eye-trackers, the primary concern in selecting a specific HRV product is the type and accessibility of the data output. At first glance the Heart Tracker 3.0 or the Heart Wizard appear to be ideal products. Each of these Biocom (Biocom Technologies: Poulsbo, WA) products is inexpensive, collects non-invasive HRV measurements, and then analyses them against individual traits, such as biological age, physical fitness, and lung capacity, in order to derive an overall health and stress measure. This single output (e.g., ranging from 1 - 100) is the ideal type of simple reading that is needed to fuel the ITS. However, further investigation has revealed that these programs are only able to provide snapshots of the user's data that are retrospectively analyzed by the researcher. The purpose of the ITS is to adapt to the user's stress level in real-time, hence the need to stream real-time data into the system.

Another product from Biocom, HRV Live!, resolves this issue. HRV Live! is designed as a professional research tool rather than a consumer-based health and wellness assessment tool. As such, it streams raw HRV data in real-time, after a 5-minute system configuration which establishes the user's HRV resting baseline. The raw data are not combined with other physical health indicators (e.g., biological age), which is not a large concern within the sample of military operators who should be in peak physical fitness. Although HRV Live! is significantly more expensive than other HRV products, it is the only product that meets the essential requirements of the ITS.

The other issue to consider that is similar to eye-trackers is the ability of the ITS to access the raw data output from HRV Live!, and interpret it's meaning relative to the student's learning. The idea is that HRV will be used to assess arousal. Depending on the content presented within the course, the student will be expected to be aroused or not. For example, when conducting a threat

assessment, low arousal levels could prompt the tutor to give hints or probes that a threat should be detected. Alternatively, if the user is over aroused (e.g., frustrated) when he or she should not be (e.g., when learning introductory material), the tutor could change the style of feedback to one more helpful.

While it is desirable to start the initial design of the ITS with a minimal amount of adaptive mechanisms to avoid confounding technological complexity, future attempts to triangulate data are recommended by incorporating a device that measures the GSR. Specifically, for using skin conductance to infer mental workload, the **GSR Temp 2X** is the recommended COTS model, while the **HandWave** is recommended as a self-constructed alternative. It is to be noted that the HandWave is a university engineered prototype developed in-house, which likely increases the difficulty of reproduction. These two products are the only technologies that are available, affordable, and unobtrusive. While the Mikron Scan also fits these categories, it was used for measuring facial skin temperature and not the GSR (and was included as an interesting alternative to the GSR, but not yet supported by enough other research to be considered for serious purchase).

In addition to specific technology purchase suggestions, a number of general use recommendations are offered to aid the ease of integration of psychophysiological measures into adaptive learning. The following section provides a list of recommendations and suggested uses for the implementation of psychophysiological technologies within the IEDD course ITS as based on the literature reviewed:

Defining the Need: The context in which the ITS will be used will be a determining factor in the choice of a psychophysiological measure. For instance, while it may be theoretically ideal to capture multiple forms of mental workload output, it may be equally undesirable to attempt to analyze, interpret, and integrate these data into one ITS.

- The reviewed research suggests that some workload measures are related (e.g., HRV and the EEG), Thus, it may be more feasible to use a single measure to infer workload.
- The issue with a more pragmatic approach to using workload metrics is that some measures, such as the GSR, may only indicate a broad presence of emotion, but not allow for further detail. It is likely then, that emotions such as frustration could be confused with arousal, which would have opposing responses from an ITS.
- In addition, the physical equipment needed to use multiple indices of mental workload will be limited by the physical constraints of the actual operators. If the ITS is intended to provide additional practice training that operators can do independently on their personal laptops, then it would be undesirable to have multiple psychophysiological monitors, as it would be very burdensome to set these up alone.
- o On the other hand, if the tutoring program is designed exclusively for use on one computer system in each military base, which could be technically supported for setup and calibration, then it may be more desirable and feasible to include more complex measures of cognitive functioning.

- The other option is to start with an uncomplicated measure such as HRV measured by a commercial product such as EmWave. Given that the EmWave is small, inexpensive, unobtrusive, and offers wireless options, it could provide a “starting” point for future investigations of adaptive learning systems as proposed by Karamouzis (2006).
- In the context of the IEDD course, an obvious source of threat: the initial detection of the IED, followed by the determination of level of threat (i.e., How much damage will the IED cause if detonated? How likely is it to be detonated? Are there snipers in the area?). In order to improve operator questioning techniques, the GSR could be paired with HRV when operators are interviewing on-scene commanders or other witnesses. The expectation would be that, when pertinent IED information is revealed, the student would show signs of increased arousal. If not, the tutor would infer that the student missed these clues, and thus could offer further hints and probes to guide his or her attention to this important information.

Assess Benchmark Data: EEG research is only recommended for very specific tasks when the EEG results are known ahead of time (i.e., bench-markers) and can be compared in order to adapt the system appropriately.

- As with any test, individual responses will vary in response to stimuli, therefore, baseline data will need to be established prior to testing so that the tutor can assess the change. Knowing only the current output would only be acceptable for something like eye-tracking, not mental workload , which varies over time.
- A further caveat to consider is the many artefacts that can produce variability within these psychophysiological measures, apart from just workload or emotion assigned to the task at hand. For example, caffeine and sugar intake are well known stimulants that affect arousal, heart rate, etc., and these substances are likely consumed by many potential operators. It may be unrealistic to expect students who are already experiencing stress due to the IEDD course exam to refrain from their daily rituals. This is so because refraining from these rituals, in fact, could further distort their results due to withdrawal symptoms.

Short versus long-term observation: It can be recommended that when defining the type and needs of the cognition monitoring technology used to adapt the system, the time span in which observation is required should be defined. This recommendation is based on findings that certain types of psychophysiological monitoring technology are better suited for long- versus short-term observation. For example, research regarding skin temperature revealed that this technology was inappropriate for quasi, real-time adaptation but that it appears to be suitable for longer-term observation and adaptivity (Blanchard, et al., 2007).

Multimodality:

- Use multiple psychophysiological measures: It is recommended that psychophysiological measures should not be implemented as a standalone tool. In other words, it is recommended that more than one cognition monitoring technology system should be used in order to “triangulate” the measures of interest. As

suggested by Blanchard et al. (2007), in order for the system to be designed as relevant for a learning activity, a particular pattern detected in a given physiological channel must be corroborated with other sources in order to confirm its meaning. Complementary data should come from other physiological signals.

- On that same note, an additional problem with multimodal measurement is the multi-fold data output that comes with it. For example, the EEG produces a vast amount of data points, which must then be interpreted meticulously by the researcher. Given that research by McCraty et al. (1995) has successfully linked the EEG to heart rate measures such as HRV, it may be appropriate to use less complex methods. Even if evidence supports EEG measurement accuracy, the likelihood of its use decreases dramatically if the process of acquiring these data is overly complicated.

Experts Required:

- As every measure is quite specific in terms of implementation, and the collection and analysis of associated data, it is recommended that an expert should be associated with the specific measures involved in ITS design.
- The current project may warrant the use of individuals who have expertise pertaining to a specific psychophysiological measure. This is because the complex data output from a particular psychophysiological measures may not be properly interpreted by the average researcher.
- Furthermore, given the multitude of confounding parameters likely to exist in any given measure alone (e.g., noise, individual differences, etc.), it is strongly recommended that the proposed ITS be tested with each psychophysiological measure separately at the start of the design.
- Within the constrained environment of the actual IED course, a concerning limitation is the inability to test between subjects, as no CF student is to be denied the best training available. As such, it is recommended to test the effectiveness of individual mechanisms on civilians who are not employed as CF IEDD operators.

6 Performance Tracking

Within performance tracking systems, the idea is to record the student's progress so that the system adapts to changing levels of the student's performance as learning increases. One note with this area of focus is that there is a lack of COTS technology available for adaptive purposes. Due to this limitation, this section includes mostly conceptual research for the purpose of recommending ideas for future use, as most technologies or software used are not available for use in the current project. While the review of performance tracking systems did reveal several areas of interest for developing technology (e.g., facial and motion tracking), the bulk of the more mature (and available) literature is housed in eye-tracking, speech recognition and language training. This section presents the results of the detailed review of attention and performance tracking.

6.1 Eye-Tracking

The collection of users' actions is not complete without an understanding of which interface features are being attended (Bednarik, 2005). Eye-movement tracking provides instant information about the location of the user's visual attention. Assuming that the object under the user's visual attention is also located on the top of his/her cognitive processing "stack," knowledge about one's gaze can help to understand which features of an interface were of interest to the observer, and in what order and how long the user attended to each feature. As eye-tracking research and technology has been reviewed extensively in Sub-section 2.1 of this report, the current section will focus on alternative forms of performance tracking in order to avoid redundant content.

6.2 Attention Tracking

Attention can be regarded as the gateway that allows information into the brain, as it is what one chooses to focus on. The human mind is bombarded with millions of stimuli and it must have a way of deciding which of this information it wishes to process. Attention is generally considered to have limited capacity, as we cannot effectively monitor all of the events in our environments at once, or for extended periods of time. With selective attention, one chooses to allocate more mental resources to a particular stimulus, while limiting others (e.g., holding a conversation in a loud party). In divided attention, one divides mental resources among multiple stimuli, which ultimately decreases the overall availability of attention for each added task (e.g., eating, while driving, while using a cell phone).

As the focus of this report is on the IEDD ITS, it is beyond the scope of this review to give a detailed review of the cognitive factors involved in attention. The general idea behind attention tracking in the context of adaptive learning is that knowing how and what the student is attending will allow the tutor to better adjust to the learner's needs. One form of attention tracking involves computer-mouse, movement tracking. Here, the user's mouse movements on a computer are considered to represent the information that is being attended to, which is similar to eye-tracking. With computer mouse tracking, the tutor can assess which portions of a webpage, for example, are the most explored by the user, and which sections remain untouched.

McQuiggan, Mott, and Lester (2008) used mouse tracking to record the areas that participants had explored on a virtual learning island in order to determine whether information should be considered new or learned. The online tutorial system monitored the amount of time spent on each question and how long the cursor resided in particular locations. The interactive environment then tracked the time elapsed since the student arrived at the last location, achieved a goal, and was presented with an opportunity to achieve a goal.

Another form of attention tracking is posture tracking. For example, Dragon et al. (2008) analyzed students' body positions and seated pressure in order to assess their level of engagement while interacting with an e-learning environment. These measurements were then correlated with other measures such as the GSR to infer how interested, frustrated or bored were the students.

6.3 Motion Tracking

The process of motion tracking can also be categorized as a form of attention tracking, but on a larger scale. Instead of analyzing discrete eye-movements or cursor tracking to infer what an individual is paying attention to, motion tracking captures full-body movement data in order to infer various aspects of cognition as based on behaviour. For example, Livak (2004) used motion tracking to assess team building clearing manoeuvres as based on stacking, crouching, and crawling behaviour on objects within the virtual environment. Sukthankar and Sycara (2005) also tracked human subjects performing various movements from a set of military manoeuvres. More specifically, the researchers tracked the subjects' motion types and their proximity to landmarks.

The transmission of realistic human motion to synthetic agents relating to a specific context is well-suited for e-learning training environments. Understanding the meaning behind physical behaviours could be an important factor to consider when designing the non-verbal aspects of the questioning technique for the IEDD course. For the purpose of this course, it may not be the large body movements like crouching and crawling that are important, so much as the hand signals and head nods that occur during conversation. On the other hand, full body movements would certainly be important during any dismounted activity within the IEDD process, such as establishing a cordon or evacuating the area. Furthermore, actions such as nervous shifting or pacing could be used to train lie detection, which could prove particularly useful in potential gaming platforms [e.g., Virtual Battle Space 2 (VBS2TM) (Bohemia Interactive Studio: Prague, Czech Republic)] where facial expression manipulation is limited. VBS2TM is a gaming platform that was designed for government agencies. It offers realistic battlefield simulations and the ability to operate land, sea, and air vehicles. It also delivers a synthetic environment for the practical exercise of the behaviours and skills that are required to successfully execute various missions.

6.4 Facial Recognition

Another way to infer cognition from explicit human behaviour is through facial recognition. This review does not cover a great depth of literature on this topic, as facial recognition is not a mature enough technology to consider at the moment. However, facial recognition is one way to automatically infer a student's emotion during learning, as based on complex algorithms that analyze the dimensions of the human face. Whitehill, Bartlett, and Movellan. (2008) found that facial recognition can be used to adjust the rate of presentation for learning content based on

emotions such as frustration and boredom. Furthermore, Craig, D'Mello, Witherspoon, and Graesser (2008) related participants' facial expressions to subjective affective states while interacting with an intelligent tutoring system.

6.5 Speech Recognition

Speech recognition systems are described as a technology that is able to recognize unrestricted speech using natural language processing. Research in this area has also focused on other related phenomena. For example, researchers have examined involuntary changes in the rate, pitch, intensity, quality and articulation of speech. All of these factors have also been associated with different emotions (Murray and Arnott, 1993).

Speech recognition (also known as automatic speech recognition or computer speech recognition) converts spoken words to text. The term "voice recognition" is sometimes used to refer to speech recognition where the recognition system is trained to a particular speaker - as is the case for most desktop recognition software (e.g. RosettaStone: Arlington, VA); thus, there is an element of speaker recognition, which attempts to identify the person speaking, to better recognize what is being said.

Speech recognition differs from voice recognition, as it is broader in scope given that it refers to a system's ability to recognize almost anyone's speech. In contrast, voice recognition is a system that is trained to a particular user, as it recognizes that user's speech based on his/her unique vocal sounds.

6.6 Results of Literature Search on Performance Tracking

The literature search on performance tracking technologies yielded several sources containing performance or attention tracking technologies that were considered relevant with respect to the current intelligent tutoring system. *Table 9* presents a list of the references examined in this literature review, classified by the type of attention tracking method examined (i.e., attention tracking, performance tracking speech recognition, and motion/face recognition).

Table 9. Performance tracking literature search: Reference list

Type	Reference
Attention Tracking	• Van Gog, Jardoza, Scheiter, Gerjets, & Paas (2009) • Jarmasz, Keillor, & Hollands (2005)
Performance Tracking	• Sukthankar & Sycara (2005) • Livak (2004)
Speech Recognition	• Kerly, Ellis, & Bull (2008) • El Saadawi et al. (2008) • RosettaStone • Johnson (2009) • Johnson & Valente (2008)
Motion/Face Recognition	• Craig et al. (2008) • Whitehill et al. (2008)

In addition, a summary of the desired qualities for performance and attention tracking are presented in *Table 10*. This table was based on a list of requirements designed to aid in the selection of the most appropriate product to implement, followed by recommendations and suggested uses for the implementation of adaptive learning of the e-learning framework of the IEDD course, as based on the literature reviewed. The technologies within the performance and attention tracking literature were evaluated based on the following criteria:

- COTS: Is this product currently available commercially, off-the-shelf?
- Affordable: Is this product within the reasonable budget to spend?
- Unobtrusive: Is this product invasive, bulky, or in any way uncomfortable so that it may affect desire to wear? Also, is it difficult to setup and calibrate alone?
- User Support: Does the product offer any form of technical support or training after initial purchase?
- Build Own: Does the product offer instructions on how to build it oneself?
- Leave for IEDD course: Can this product remain in CFB Galetown for use by the IEDD course students when the project is completed?
- Quality: Has this product been supported by scientific research (i.e., high quality)? If not, does it appear to be usable by the medical/scientific community, or is it a commercial-only product without any form of validation (i.e., low quality)?

Table 10. Summary of Requirements Checklist for Attention Tracking Mechanisms

Style	Product	COTS	Affordable	Unobtrusive	User Support	Build Own	Leave for IEDD Course
Attention Tracking	Tobii 1750 (Tobii Technology: Sweden)	Yes	No	Yes	No	No	Yes
Performance Tracking	Wayang Tutor (Wayang Outpost: Amherst, MA)	Yes	Yes	N/A	N/A	No	No
	Crystal Island with Self arch (NC State University: Raleigh, NC)	No	N/A	N/A	No	Yes	No
	CALMsystem (University of Birmingham: Birmingham, UK)	No	N/A	N/A	No	Yes	No
	Report Tutor (University of Pittsburgh School of Medicine: Pittsburgh PA)	No	N/A	N/A	No	Yes	No
	RosettaStone (Arlington, VA)	Yes	Yes	N/A	No	Yes	Yes
Speech Recognition	Alelo™, Tactical Dari (Alelo: Los Angeles, CA)	Yes	Yes	Yes	maybe	Yes	Yes
Motion/Face Recognition	MOU, Unreal Tournament (Carnegie Mellon University: Pittsburgh, PA)	No/Yes	Yes	No	No	Yes	No/Yes
	AutoTutor (University of Memphis: Memphis, TN)	No	N/A	No	No	Yes	No

6.7 Recommendations and Suggested Use

Ultimately, the review of performance measures and attention tracking was lacking in COTS products that realistically could be implemented in the IEDD ITS. The most applicable research stemmed from AutoTutor, which described a program to help medical students identify patterns in X-ray scans, however, the scan and zoom process used in this program is not directly transferable to the IEDD course in terms of product, only conceptually so. Other programs, such as the modified Unreal Tournament offer interesting ideas for using motion tracking as an objective and non-invasive method of tracking performance. However, these ideas are also academic in nature and are not easily accessible for this project. Equally, the RosettaStone training program tracks performance, tailors programs to the user, and specifically trains new languages. However, RosettaStone does not use open-source code that could be readily adapted by the proposed IEDD ITS.

Alelo™ presents an interesting platform to incorporate culture-based training to the IEDD operators. Alelo™'s Tactical Language and Culture Training System (TLCTS) uses cultural analysis and instructional design (Situating Culture Methodology) to facilitate the creation of training courses, focusing on sociocultural and sociolinguistic data collection on situation that trainees are most likely to encounter in the context of their job or mission context. It supports knowledge and skill acquisition, and skill transfer. Alelo™ products are available as stand-alone courses, embedded in other courses and simulations, or blended with other instruction modalities. Every course is specifically designed to match the profile of its target students, accounting for factors like their age, native language, cultural background, native country, prior knowledge of the target language, desired level of fluency, and application (business, professional, tourism, etc.).

The IEDD Operator Course represents an ideal application for speech recognition systems like Alelo™. Currently, the course is designed to train the Number 1 individual (leader), while the Number 2 (assistant) must be a role played person overly qualified for this position (i.e., other Number 1 trainees or course instructors). Hence, the Number 1 team position requires a person to act as a "pseudo-assistant", engaging in a voice dialog, which simulates the dialog which the Number 1 would have to conduct with the Number 2 individual in real IEDD situations. Speech recognition and synthesis techniques offer the potential to eliminate the need for a person to act as pseudo-assistant, thus reducing training and support personnel

Speech recognition systems enable the intelligent tutor to detect and correct speakers' dysfluency and pronunciation, and to provide feedback to improve the speakers' interpersonal and communication skills. This application would be helpful within the proposed ITS design with respect to questioning technique, as questioning involves interviewing civilian witnesses from diverse backgrounds, which requires the ability to converse in foreign languages.

Sensitivity to diverse cultures and languages is surely needed when conducting interviews of high importance regarding IED's. However, similar to RosettaStone, the limited access of COTS systems are an obstacle to using existing speech recognition systems within the IEDD course as opposed to constructing a new system from basic components. In brief, the following is a list of key issues and recommendations regarding the implementation of performance tracking measures as based on the current review:

- The majority of technologies are not available COTS systems. Those that are, are only gaming platforms; any intelligent portions are developed in-house [e.g., use of Military Operations in Urban Terrain (MOUT)].
- Alelo™ appears to be most promising because it already has developed training programs for military culture training. However, it is unclear whether or not those programs could be integrated into the IEDD ITS. It may be that Alelo™ can be used for inspiration only, while the proposed ITS will be built using an authoring tool compatible with VBS2™.
- Speech integration would be ideal, but this technology is not mature enough at this time.
 - An alternative to using actual speech recognition may be to use text-based selections that are pre-determined in the system, but that are only read out loud when selected by the user. That way, it would be more realistic to hear the specific intonations and inflexions in the speech that are involved in different types of questions, instead of only being able to read the phrase and infer these qualities in one's head.
 - Perhaps the interviewer (i.e., student) could “try the question out” before selecting it. For instance, the interviewer could scroll over each sentence to hear what it would actually sound like before deciding to vocalize the sentence to the interviewee.

In summary, the only concrete recommendations that can be made at this time are to further investigate Alelo™ to determine the accessibility of the architectures that they have authored within the VBS2™ gaming system.

7 Recommendations and Conclusions

This report reviewed current techniques and technologies relating to eye-tracking, physiological indices of workload and stress, cognitive learning styles and performance tracking that have been successfully used, or could theoretically be used to augment an ITS. The purpose of the review was to provide straightforward, applicable recommendations that would lead to the purchase of technology that can be implemented into the IEDD ITS.

Eye-tracking as a means of attention, workload, and expertise measurement proved to be the most mature and commercially accessible technology used in research. The recommended style of eye-tracker is a desktop or screen-integrated eye-tracker, as these are the most non-invasive types of eye-trackers, and they take the least time to set up and calibrate as compared to head-mounted eye-trackers. Goggle style eye-trackers are appealing for their mobility, but are unnecessary and costly for use in front of a PC. The main limiting factor is price, as the high quality models that are frequently used in research tend to cost over \$40,000. The suggested quality/price compromise is to purchase one mid-range (\$10,000 or less) eye-tracker (such as the EasyGaze system) for use in the collection of baseline data and the calibration of other systems. If numerous eye-trackers are needed because they are to be left at the IEDD course, it is recommended that open-source, or web-cam-based alternatives be used, as these can be calibrated against a mid-range eye-tracker that is also recommended for purchase.

It is recommended that the ILS (Felder & Solomon, 2006) be administered to students prior to their use of the IEDD ITS. The ILS has proven validity and reliability, is freely available and automatically scored online, and takes only a few minutes to complete. It is further recommended that the ILS be administered during baseline testing in order to get a sense of any dominant learning styles. These results would help provide guidance for content building within the actual ITS (e.g., if there was a preference for visual over auditory learning styles among students).

The EEG, while a valuable and proven source of information about mental workload and other cognitive functions, is not recommended as a form of adaptive measure within the IEDD ITS. First and foremost, the equipment and set-up time required to acquire accurate EEG recordings makes it unlikely to be usable by IEDD operators without assistant or researcher supervision. The IEDD ITS needs to be a stand-alone learning companion that is readily accessible to students. If the IEDD ITS requires an hour for placing gels and electrodes on one's scalp, it is doubtful that it will be used beyond pure research purposes when the experimenter is present.

The psychophysiological measures recommended for use are the HRV and the GSR in either a simple ear-clip, or via a wireless Bluetooth model. Both measures have feasible, non-invasive techniques for assessment, and could be used in combination to help triangulate a more accurate meaning of general arousal to specific stimuli. The primary technology recommended for purchase is the HRV Live!, while the GSR Temp 2x is recommended for future data triangulation.

Performance tracking measures produced the smallest number of tangible technologies that could be implemented into the IEDD ITS. While motion tracking offered some interesting research streams for performance tracking as based on posture, at this point, the related technologies are only academic prototypes. The most plausible form of performance tracking appears to be speech

recognition. This has matured in the field of language training as in RosettaStone, but is still in need of improvement for AleloTM. The problem is that the project is not in need of a language training just yet, so this technology is likely too complex and not reliable enough to use yet. As for AleloTM, the style of its interactive and mobile training is certainly appealing – the question is: can the application itself can be integrated into the IEDD ITS?

In summary, the results of the literature review pertaining to adaptation mechanisms demonstrate a range of maturing technologies that can be usefully applied to the development of an intelligent tutoring system designed to augment the IEDD Operator Course. In brief, the products recommended for immediate purchase are:

- Eye-tracker: EasyGaze – Design Interactive.
- Psychophysiological: HRV live! – Biocom.
- Performance Tracker/Mobile Application: Tactical Dari (tentative) – AleloTM.

Once these technologies are acquired, studies need to be carried out to investigate design and implementation approaches for integrating these technologies with the IEDD Operator Course. An ITS evaluation plan also needs to be developed to assess the effectiveness of these ITS adaptation mechanisms on IEDD training.

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List of abbreviations

AOI	Area of Interest
ASSIST	Approaches and Study Skills Inventory for Students
CBR	Chemical, Biological, Radiological
CF	Canadian Forces
CFB	Canadian Forces Base
COTS	Commercial-Off-the-Shelf
CR	Corneal Reflection
CSI	Cognitive Styles Index
CSQ	Cognitive Style Questionnaire
DC	Direct Current
DND	Department of National Defence
DRDC	Defence Research and Development Canada
ECG	Electrocardiogram
EDR	Electrodermal response
EEG	Electroencephalogram
EMG	Electromyograph
EOG	Electrooculograph
ERP	Event Related Potential
GSR	Galvanic Skin Response
HR	Heart Rate
HRV	Heart Rate Variability
IED	Improvised Explosive Device
IEDD	Improvised Explosive Device Disposal
ILS	Index of Learning Styles
ITS	Intelligent Tutoring System
LOCATE™	A software tool designed at DRDC that aids in the design of workspaces using learning styles
LSI	Learning Style Inventory
MBTI	Myers-Briggs Type Indicator
MOUT	Military Operations in Urban Terrain
NASA TLX	National Aeronautics and Space Administration Task Load Index
NATO	North Atlantic Treaty Organization
PC	Personal Computer
PGR	Psychogalvanic reflex
R&D	Research and Development
RSP	Render Safe Procedure
SCR	Skin Conductance Response
SDK	Software Developer's Kit
TLCTS	Tactical Language and Culture Training System
US	United States
VBS2™	Virtual Battle Space 2

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DOCUMENT CONTROL DATA (Security classification of the title, body of abstract and indexing annotation must be entered when the overall document is classified)		
1. ORIGINATOR (The name and address of the organization preparing the document, Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's document, or tasking agency, are entered in section 8.) Publishing: DRDC Toronto Performing: DRDC Toronto Monitoring: Contracting:		2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.) UNCLASSIFIED
3. TITLE (The complete document title as indicated on the title page. Its classification is indicated by the appropriate abbreviation (S, C, R, or U) in parenthesis at the end of the title) Suitable Adaptation Mechanisms for Intelligent Tutoring Technologies (U) (U)		
4. AUTHORS (First name, middle initial and last name. If military, show rank, e.g. Maj. John E. Doe.) Ming Hou, Suzanna Sobieraj, Chelsea Kramer, Jana Lee Tryan, Simon Banbury, Kristine Osgoode		
5. DATE OF PUBLICATION (Month and year of publication of document.) December 2010	6a NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.) 68	6b. NO. OF REFS (Total cited in document.) 94
7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of document, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.) Technical Report		
8. SPONSORING ACTIVITY (The names of the department project office or laboratory sponsoring the research and development – include address.) Sponsoring: Tasking: DRDC Toronto		
9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant under which the document was written. Please specify whether project or grant.) 14av		9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.) W7711-098153
10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document) DRDC Toronto TR 2010-074		10b. OTHER DOCUMENT NO(s). (Any other numbers under which may be assigned this document either by the originator or by the sponsor.)
11. DOCUMENT AVAILABILITY (Any limitations on the dissemination of the document, other than those imposed by security classification.) Unlimited distribution		
12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, when further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.) Unlimited announcement		

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(U) This report summarizes the results of a literature review conducted to recommend suitable adaptation mechanisms for an intelligent tutoring system (ITS). Intelligent Tutoring technologies have been identified by Defence Research & Development Canada – Toronto as an effective training aid for the Canadian Forces (CF). A specific CF training course, the Improvised Explosive Device Disposal (IEDD) Operator Course, has been identified as a target for the implementation and evaluation of intelligent tutoring technologies. The review involved surveying and synthesizing applicable literature to develop recommendations and best practices pertaining to the integration of these technologies into an ITS for the IEDD Operator Course to improve questioning skills. The recommended four adaptation mechanisms for implementation into the IEDD ITS were as follows:

- Eye-tracking technologies to support attention tracking
- Cognitive learning styles to support customization of the learning environment
- Psychophysiological indices to support cognitive state monitoring; and
- Performance measures to support engagement tracking.

(U) Le rapport présente les résultats d'une analyse documentaire visant à recommander des mécanismes d'adaptation appropriés pour un système tutoriel intelligent (STI). Des technologies de tutorat intelligent ont été déterminées par Recherche et développement pour

la défense Canada (RDDC) – Toronto en tant qu'outil efficace d'aide à l'instruction des Forces canadiennes (FC). Un cours particulier d'instruction des FC, le Cours d'opérateur de la neutralisation des engins explosifs improvisés (IEDD), a été identifié comme convenant à la mise en œuvre et à l'évaluation des technologies de tutorat intelligent. L'analyse consistait à étudier et à résumer les documents pertinents afin de formuler des recommandations ainsi que d'établir les meilleures pratiques relatives à l'intégration de ces technologies en un système tutoriel intelligent pour le Cours d'opérateur IEDD afin d'améliorer les aptitudes d'interrogation. Les quatre mécanismes d'adaptation que l'on propose de mettre en œuvre dans le STI IEDD sont les suivants :

- technologies de suivi du regard à l'appui du suivi de l'attention
- styles d'apprentissage cognitif à l'appui de l'adaptation de l'environnement d'apprentissage
- indices psychophysologiques à l'appui du suivi de l'état cognitif
- indicateurs de rendement à l'appui du suivi de l'engagement

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(U) learning style, cognitive style, adaptive learning, intelligent tutoring, computer-based training, e-learning, distance learning, learning customization, training technology, adaptation technique, eye tracking, physiological index, attention tracking, performance tracking, engagement tracking, learning effectiveness, real-time feedback, improvised explosive device disposal

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