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Suitable Learning Styles for Intelligent Tutoring Technologies

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Abstract

This report summarizes a study examining suitable cognitive and learning styles for intelligent tutoring technologies to improve the Canadian Forces (CF) distance learning capability. The study was motivated by the CF's requirement for computer-based training in a distance educational context to improve learning effectiveness. Through extensive research, Defence Research and Development Canada (DRDC) - Toronto has deemed that advanced e-learning systems are the appropriate tool to address CF learning needs, as e-learning systems:

- Cater to all individuals in the CF regardless of their cognitive or learning style;

- Allow CF personnel to work at their own pace and remotely;

- Cut costs and optimizes learning productivity;

- Equip the CF and DRDC with emerging and cutting edge technologies; and

- Advance the knowledge base of defence science.

The study involved collating applicable academic research literature to gather data. Potential suitable cognitive and learning styles for Intelligent Tutoring Systems (ITSs) were examined and analyzed. Although most cognitive and learning styles were inconclusive and indefinite due to a lack of independent validation data, the Felder Solomon Learning Styles Index has been validated. Thus, it is recommended to be used in an ITS to identify students' learning styles for the customization of their learning experience.

Résumé

Ce rapport résume une étude qui examine des styles cognitifs et apprentissages appropriés pour les technologies des tuteurs intelligents, pour améliorer le potentiel de la formation à distance des forces canadiennes (FC). L'étude a été motivée par la condition du FC pour la formation assistée par ordinateur dans un contexte de formation à distance pour améliorer l'efficacité d'apprentissage. A travers de la recherché approfondie, Recherche et développement pour la Défense Canada- Toronto a considéré que les systèmes d'apprentissage en ligne se sont l'outil approprié pour adresser les besoins d'apprentissage du FC, comme systèmes d'apprentissage en ligne:

- Satisfaire les besoin de tous les individus dans les FC indépendamment de leur style cognitif ou apprentissage ;

- Permettre au personnel de FC de travailler dans leur propre rythme et à distance;

- Réduire les coûts et optimiser la productivité d'apprentissage ;

- Équiper les FC et le RDDC avec des technologies émergeant et tranchant et

- Progresser la base de connaissance de la science de la défense

L'étude a impliqué l'assemblage de la littérature de la recherche académique appliquée pour collecter les données. La styles cognitifs et d'apprentissage approprie pour les systèmes tuteur intelligents (STI) ont été examinés et analysés. Bien que la plupart des styles cognitifs et d'apprentissage n'aient pas été concluants et indéfinies à cause d'un manque de validation indépendante des données, l'index d'apprentissage de Felder-Solomon a été validé. Ainsi, il est recommandé de l'utilisé dans un STI pour identifier les styles d'apprentissage des étudiants pour la customisation de leur expérience d'apprentissage.

Executive summary

Suitable Learning Styles for Intelligent Tutoring Technologies:

Ming Hou, Suzanna Sobieraj, Sylvain Pronovost, Shelley Roberts, and Simon Banbury; DRDC Toronto TR 2010-073; Defence R&D Canada – Toronto; May 2010.

As the Canadian Forces (CF) demonstrate their readiness for distance learning, it is imperative to understand the challenges that may accompany the technology and approaches used. Defence Research and Development Canada (DRDC) – Toronto has recognized these challenges and in response started an Applied Research Project (ARP) in 2008. The objective of this ARP is to advance the knowledge base of defence science, investigate novel and emerging distance learning technologies, and explore the military application of those technologies within the CF.

One of the most challenging activities for a distance education facilitator will be to provide the same or higher degree of responsiveness as a tutor to the students and to customize the learning experience to an individual's learning style. One of the mechanisms to facilitate the learning experience is adaptive learning through 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 a student's learning experience.

The objective of this investigation was to identify suitable learning styles for intelligent tutoring systems (ITSs) that would improve CF distance learning capabilities. In this investigation, 13 of the most influential cognitive and learning styles were reviewed as based on previous literature. The review found no empirical evidence for the reliability, validity, and applications of the 13 models. Then, the research was extended to search for literature pertaining to cognitive and learning styles from scientific, defence, government and internet-based sources. The search yielded the Felder-Solomon's Index of Learning Styles (ILS) which has strong empirical support. Additionally, DRDC has developed an ILS-based learning aid for a workplace design software called LOCATE^{TM}. Thus, it is recommended that the ILS should be used as a model in an ITS to identify the learning styles of CF learners undergoing computer-based training to improve their learning effectiveness.

Sommaire

Styles d'Apprentissage Appropriés pour les Technologies Tuteurs Intelligents:

Ming Hou, Suzanna Sobieraj, Sylvain Pronovost, Shelley Roberts, and Simon Banbury; DRDC Toronto TR 2010-073; R & D pour la défense Canada – Toronto; Mai 2010.

Pendant que les forces canadiennes (FC) démontrent leur empressement pour la formation à distance, il est impératif de comprendre les défis qui peuvent accompagner la technologie et les approches utilisées. Recherche et développement pour la Défense Canada (RDDC)-Toronto a identifié ces défis et par conséquent, un projet de recherche appliquée (PRA) est lancé en 2008. L'objectif du PRA est de progresser la base de connaissance de la science de la défense, étudier des nouvelles et émergentes technologies de formation à distance et explorer l'application militaire de ces technologies au sein du FC.

Une des tâches les plus provocantes pour un facilitateur de la formation à distance sera de fournir un degré de réceptivité aux étudiants équivalent à ou plus élevé qu'un professeur et de personnaliser l'expérience d'enseignement au style d'apprentissage d'un individu. Un des mécanismes pour faciliter l'expérience d'enseignement est un apprentissage adaptif grâce aux technologies des tuteurs intelligents. Pour rendre la technologie efficace dans un environnement de formation à distance, les styles d'apprentissage de chaque étudiant doivent être examinés avant de mettre en oeuvre la technologie, afin de faciliter la personnalisation d'une expérience d'apprentissage pour chaque étudiant.

L'objectif de cette recherche était d'identifier des styles d'apprentissage appropriés pour les Systèmes Tuteurs Intelligents (STI) qui amélioreraient le potentiel de la formation à distance pour les FC. La recherche a examiné 13 styles cognitifs et d'apprentissage les plus influents basé sur la littérature précédente. La révision n'a trouvé aucune évidence empirique pour la fiabilité, la validité, et les applications des 13 styles. Ensuite, la recherche a été prolongée pour évaluer la littérature concernant des styles cognitifs et d'apprentissage d'après des sources scientifiques, défensives (par exemple, la défense des USA et des rapports de l'OTAN), gouvernementales (par exemple, archives de RDDC) et sur Internet. La recherche a mené à l'Index d'Apprentissage de Felder-Solomon (ISA) qui a un appui empirique fort. En plus, RDDC a développé une aide d'apprentissage basée sur ISA pour le logiciel de conception des lieux de travail appelé LOCATE^{TM}. Ainsi, il est recommandé qu'ISA devrait être employé comme modèle dans un STI pour identifier les styles d'apprentissage des FC, qui subissent la formation assistée par ordinateur pour améliorer leur efficacité d'apprentissage.

Table of contents

List of tables

List of figures

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1   Introduction

This document presents the results of a literature review examining suitable cognitive and learning styles for intelligent tutoring technologies. This review was motivated by the requirements of the Canadian Forces (CF) for computer-based training in a distance educational context to improve learning capabilities and effectiveness.

1.1   Background

As the CF demonstrate their readiness for distance learning it is imperative to understand the challenges that may accompany the technology and approaches used. Defence Research & Development Canada (DRDC) – Toronto has recognized these challenges and in response started an Applied Research Project (ARP) in 2008. The objective of this ARP is to advance the knowledge base of defence science, investigate novel and emerging distance learning technologies, and explore the military application of those technologies within the CF.

One of the most challenging 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 computer-based distance learning experience is adaptive learning and intelligent tutoring technology.

Computer-based learning and distance education have been implemented for many decades now. With ever increasing demands for specialized knowledge and quality services, computer and distance education have evolved into a myriad of methodologies to satisfy such needs. Adaptive learning and intelligent tutoring technologies are two such methodologies.

One of the best summaries of computer-based and distance learning technologies, such as intelligent tutoring systems (ITSs) and e-learning, comes from Shin, Yoon, Lee, and Lee (2002), who provide the following taxonomy of the four main types of computer-based educational systems:

- *Computer-aided instruction systems*: the most ubiquitous systems, and these are aimed at facilitating the transfer of educational content without any particular commitments to similarities between the interface and the actual contents of the subject matter.

- *Multimedia and virtual laboratories:* use advanced computer graphics and multimedia technologies to represent some aspects or the whole of the subject matter contents as realistically as possible.

- *Distance learning systems and instruction on the web:* connect learners and instructors through the use of Internet architecture, thereby allowing both synchronous and asynchronous learning, and giving the instructor greater freedom as he or she does not have to directly manage the education session.

- *Intelligent tutoring systems:* completely self-regulating systems for the control, delivery, and assessment of learning content. In these systems, human instructors are no longer required and instead, complex algorithms are designed to rely on feedback from the learners' performance, prior exposure to knowledge, and learning rate to deliver, evaluate, and react according to some pedagogical principles, educational goals, and implementation tools.

On the whole, it is critical to note that if computer-based and distance learning technologies are to be rendered effective methods of instruction, then student learning styles need to be investigated prior to implementing any such technology so as to facilitate the customization of each student's learning experience. This becomes especially important when implementing adaptive learning and intelligent tutoring technologies, as these systems operate based on feedback from each learner as pertaining to his or her unique repertoire of knowledge, skills, abilities, and performance.

1.2   Objectives

The objective of this review was to identify suitable cognitive and learning styles for adaptive learning and intelligent tutoring technologies that would improve CF learning capabilities. Because different students approach learning tasks and interact with learning environments in different ways, they develop a specific set of learning behaviours with which they are comfortable. Such perspectives have led to suggestions of tailoring educational interactions to students' cognitive or learning styles in the context of computer-based and web-based learning environments. The flexibility offered by such environments should enhance learning, allowing students to develop personal navigation patterns and interaction behaviour that reflects their own cognitive characteristics.

The objective of this review was achieved by reviewing theories of student learning styles, relevant technologies to best exploit the different styles in education and training principles, and methodologies of implementations in learning environments, particularly in distance/e-learning environments.

1.3   Method

In this report, 13 of the most of the most influential cognitive and learning styles were critiqued as based on a comprehensive in-depth review of 71 cognitive and learning styles conducted by Coffield, Moseley, Hall, & Ecclestone (2004a, b). Seventy one styles were evaluated on the potential relevance to the educational system in the United Kingdom (UK). To date, Coffied et al's review is the single and most impartial review of the literature on cognition, learning, and pedagogy. The 13 learning styles reviewed in this 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.

The review highlighted a lack of independent support for the reliability, validity, and applications of the models reviewed by Coffield et al. Therefore, it was concluded that there was a lack of substantial evidence to select any one theory for integration into CF adaptive learning and intelligent tutoring systems. Thus, the research was extended in an attempt to locate new learning styles that had not been reviewed by Coffield et al., and/or to provide more concrete evidence for the reliability and validity of the styles that had already been examined. Scientific, defence (e.g., United States defence and North Atlantic Treaty Organization reports), government (e.g., DRDC archives) and internet-based sources were searched for literature pertaining to cognitive and learning styles. The search yielded the Index of Learning Styles (ILS; Felder & Silverman, 1988; Felder & Solomon, 2006). Literature pertaining to the reliability, validity, and applications of the ILS was thoroughly examined and summarized.

1.4   Scope

The structure of this document is described below:

- *Section 1*. Presents an overview of the current project, and provides a brief introduction to cognitive and learning styles, and computer-based/distance learning technologies within the context of the CF;

- *Section 2*. Introduces the concepts of learning styles, and provides an overview of the different trends and popular models in the literature from the fields of cognitive and educational psychology as based on Coffield et al.'s comprehensive review of cognitive and learning styles;

- *Section 3*. Presents a detailed overview of the Felder-Solomon Index of Learning Styles (Felder & Silverman, 1988; Felder & Solomon, 2006). The impetus for examining this recent model came from the lack of independent support for the reliability, validity, and applications of the models reviewed by Coffield et al. In addition, an adaptive learning aid (LOCATE^{TM}), which is based on the ILS and has been designed within DRDC to aid in the design of workspaces using learning styles is introduced; and,

- *Section 4*. Presents overall recommendations as based on the previous three sections; and,

- *Section 5*. Presents final conclusions.

2 Cognitive and Learning Styles

2.1 Overview

This section introduces the concepts of cognitive and learning styles, and provides an overview of the different trends and popular models in the literature from the fields of cognitive and educational psychology.

2.1.1 Definitions

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, 1998). 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, 1997). 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. Anderson's (2008) definition of cognitive learning style illustrates the interchangeable nature of these two terms:

> *"Cognitive learning styles are 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."*

Importantly, cognitive style (or cognitive learning style) differs from learning style as learning styles can be considered to vary over time and space (Valley, 1997), while cognitive styles are considered to be more fixed in nature. According to Valley:

> *"Learning styles can be considered to cover a much broader range of approaches to learning, often consider factors that can vary for the individual, e.g., an individual's learning style could differ according to the subject s/he is studying, the mode of assessment employed or even the amount of time available."*

Indeed, Sadler-Smith (1996) considers learning styles and cognitive styles to be "fundamentally quite distinct and having differing but complementary implications for the design of teaching." Therefore it is important to understand that differences exist between these two constructs and that both should be taken into consideration in the implementation of adaptive technologies that use cognitive and learning styles as user models. It is important to note that in this report we use the term "Learning Styles" to refer to all cognitive and learning styles.

2.1.2 A continuum of models: Coffield et al.'s families of learning styles

Considering the popularity that cognitive and learning styles have enjoyed over the last four decades, very little research has been conducted to compare and contrast the many cognitive and learning style models. Most reviews are of single models, comparisons between different versions of the same psychometric tests, or rarer, comparisons between only a small sub-set of the models. The present review is based predominantly on Coffield et al.'s comprehensive, in-depth review of cognitive and learning styles which were evaluated on the potential relevance to the educational system in the United Kingdom. To date, Coffield et al.'s review is the single and most impartial review of the literature on cognition, learning, and pedagogy.

Although Coffield et al. cite 71 learning style models in their review; they only examined the 13 most influential models in depth. The criteria for selecting particular models for examination in depth were as follows:

- The texts chosen were widely quoted and regarded as central to the field as a whole;

- The learning style model was based on an explicit theory;

- The publications were representative of the literature and of the total range of models available (e.g., experiential, cognitive and brain dominance);

- The theory has proved to be productive – that is, leading to further research by others; and,

- The instrument/questionnaire/inventory has been widely used by practitioners – teachers, tutors or managers.

Furthermore, the criteria used to reject other model were as follows:

- The approach was highly derivative and added little that was new; for example, the names of the individual learning styles, but little else, had been changed;

- The research's primary focus was on an allied topic rather than on learning styles directly; for example, it was a study of creativity or of teaching styles;

- The publication was a review of the literature rather than an original contribution to the field;

- The study was a standard application of an instrument to a small sample of students, whose findings added nothing original or interesting to theory or practice; and,

- The methodology of the study was flawed.

Coffield et al. organise their review of the 13 most influential learning style models based on criteria such as flexibility, influence by the context and environment, determination by biological and cognitive constraints, and relationship to other scientific concepts and theories. On one end of the continuum are theories that envision learning as derived from fixed factors, which are dependent on cognitive styles more so than learning styles. In these theories, researchers make strong claims regarding the genetic inheritance of the cognitive factors involved in learning styles, drawing on neural and physiological constraints such as modality-dependence (visual, auditory, tactile, etc.) and cerebral lateralization of cognitive functions. The other end of the continuum is populated by views of learning styles (rather than "cognitive" styles) as flexible preferences, strategies, and approaches that are heavily influenced by context, other cognitive

features, and personality traits. The following five *families* of learning styles follow Coffield et al.'s comprehensive literature review, and section 2.2 reviews 13 models and theories that fall along this continuum, anchored on one end by fixed *cognitive* styles and on the other end by flexible *learning* styles. Figure 1 provides an illustration of this continuum and the associate five families of learning styles that followed Coffield et al.'s review.

Figure 1. A continuum of models: Coffield et al.'s families of learning styles

2.1.2.1 Learning styles as fixed features of cognition and behaviour

On one end of the continuum, these models belong to a paradigm that emphasizes the stability, rigor, or immutability of cognitive features influencing individual learning styles. These models base their theoretical claims on a number of theories in the life sciences, such as population genetics and inheritability of traits. Cognitive style models typically depend on established correlations between genetically recurring mental and personality traits and students' preferred modes of information acquisition.

2.1.2.2 Learning styles based on architectural and structural features of the mind

Other researchers envision equally strong claims on the stability and robustness of cognitive factors influencing the learning styles of individuals, but focus on structural properties of the mind instead of genetic, neurophysiological, neuroanatomical, or physiological factors. For example, Messick (1984; as cited by Coffield et al.) argues that learning styles are the products of enduring structural features of cognitive processes, shaped by the organism and its development

through interactions with the environment in the more significant developmental phases. Contextual effects, training, and interactions with others are thus very unlikely to have an impact on cognitive and personality-driven learning styles as such styles are dependent on deeply-grounded features of the architecture of the mind.

2.1.2.3 Learning influenced by stable personality traits

This view examines the relationship between intelligence and personality and is focused on framing learning styles as dependent characteristics of personality traits. This more moderate stance on cognitive and learning styles positions itself at the median along Coffield et al.'s continuum of learning style models. Moving from biological and cognitive factors to individual inclinations based on patterns of observable behaviours introduces a trade-off in the analysis of correlations between dependent and independent variables. An increase in flexibility and interpretation of what constitutes personality types and traits gives rise to more vagueness and ambiguity in the design of measures of learning styles.

2.1.2.4 Learning styles as stable/flexible preferences

Kolb's (1984; as cited by Coffield et al., 2004a, 2004b) seminal work on learning and education rooted from what he called an "experiential" perspective is the basis of yet another family of learning styles, where researchers are interested in the dynamic aspects of learning styles and preferences of individuals. Some observations about learning preferences point towards variability in the precision and recurrence of such preferences in educational or business contexts. Individuals may manifest strong and inflexible preferences in certain contexts or for certain subject matters, whereas they are less conservative in other situations or for different areas of knowledge. Analyzing the learning styles of individuals in terms of their preferences and inclinations evades the principled, yet unsatisfactory, paradigm of strict biological or cognitive fixation of the learning experience, as some assumptions about stability are dropped to the benefit of more flexible constructs. Nevertheless, as with learning styles conceived as dependent on stable personality types, the complex interrelations between mental, behavioural, and learning characteristics make such models equally susceptible to the pitfalls of ambiguity, under-specification, and are more difficult to validate.

2.1.2.5 Learning approaches, strategies, and metacognitive factors

On the other end of the continuum (as can be seen in Figure 1), the family of learning style models are holistic in scope, taking into account the complex interrelations between individuals, contexts, and environments. Here, learning styles are viewed from a top-down perspective, where individual learning is characterized as approaches and strategies rather than styles. This family of models focuses mainly on pragmatic concerns about learning, education, and pedagogy rather than trying to tackle determinant factors that may explain how the body and mind determine learning styles. The emphasis is on individual and task dynamics, where learning is viewed as the way an individual chooses to deal with task demands, not on predisposed cognitive factors without context. One consequence is the difficulty of creating rigorous measures of learning strategies from the complexity of such multi-factorial models of learning.

2.2   Review of Learning Style Models

The following section reviews the 13 most influential learning style models. The following figure categorises each of the models in terms of Coffield et al.'s families of learning style models.

In addition, each model is described in terms of:

- *Overview and Design of Model*. An introduction to the origins and conceptual basis of the model, plus a more detailed description of the model itself;

- *Reliability and Validity*. A summary of the reliability (i.e., consistency of measurements) and validity (i.e., the degree to which conclusions about causes of relations are likely to be true) of the model;

- *Implications for Pedagogy and Evidence of Pedagogical Impact*. A summary of implications of the model on pedagogy and the evidence pertaining to its pedagogical impact; and,

- *Applications*. An illustration and summary of the domains that the model has been applied to. Specifically,

  - Classroom (includes all aspects of primary, secondary and higher education);

  - Business (e.g., corporate training and professional development); and,

  - E-learning (i.e., a form of learning in which the instructor and student are separated by space or time where the gap between the two is bridged through the use of online technologies).

2.2.1   Dunn and Dunn's Model and Instruments of Learning Styles

2.2.1.1   Overview and design of model

Dunn and Dunn's model (Dunn and Griggs, 2003) is considered by Coffield et al. to be one that presents cognitive learning style and preference from a low-level, bottom-up view of individual learning characteristics, (i.e., learning styles as constitutionally fixated features based on genetics, trait inheritance, and the interdependence of personality with cognitive processes). Dunn and Dunn's view nevertheless acknowledges that such cognitive features may be influenced by the environment, but their framework envisions such traits as stable ones working along with flexible and interchangeable characteristics.

According to Dunn and Dunn, there are four types of factors that influence cognitive learning features; namely emotional, sociological, psychological, and physiological factors. From these sources of influence, Dunn and Dunn parameterized four variables influencing individual learning styles; environmental, emotional, physical, and sociological variables. The environmental variables span from sound and temperature, to light and the design of learning environments; emotional variables are motivation, sense of responsibility, persistence, and the need for structure. The physical variables, probably the most well known component of Dunn and Dunn's model, are the VAKT components (visual, auditory, kinesthetic and tactile learning modalities), but also include other secondary components such as nutrient intake, circadian rhythm, and mobility

factors. Finally, the sociological variables are preferences for learning in groups, the support of authoritative figures, individual or collaborative work, and motivational input from family and tutors.

2.2.1.2   Reliability and validity

The proponents of the Dunn and Dunn's model put a considerable amount of faith in the tools they have created such as the Dunn and Dunn Learning Style Questionnaire and the Dunn and Dunn Learning Style Inventory. Of importance are the numerous attempts to quantify the effect size of matching pedagogical strategies and means with the modal preferences of learners. A quantitative synthesis of experimental research conducted between 1980 and 2000, in which the Dunn and Dunn Learning Style Model was used, was conducted by Lovelace (2005). The results overwhelmingly supported the position that matching students' learning-style preferences using the Dunn and Dunn model with complementary instruction improved academic achievement and student attitudes toward learning. The Dunn and Dunn model had a robust moderate-to-large effect that was practically and educationally significant.

Modality preferences sit at the heart of the Dunn and Dunn model of learning styles and preferences. It is argued that such a paradigm may not provide insightful information on pedagogical strategies nor on learning performance (Kavale & Forness. 1987; Grigorenko and Sternberg, 1995; Knapp, 1994; Shwery, 1994). These researchers argue that there appear to be important design flaws in the soundness of the assumptions underlying the psychometric tests of Dunn and Dunn, caused by a lack of independent validation for the theoretical claims and empirical support embraced too simplistically by the authors.

2.2.1.3   Implications for pedagogy and evidence of pedagogical impact

The proponents of Dunn and Dunn make equally strong claims. Supporters argue that students have individual learning style preferences which are measurable and can be validated via self-tests and psychometrics. By tailoring pedagogy to individual learning styles, performance increases, and this in turn increases motivation and achievement among learners. Importantly, students who are less successful may benefit even more significantly from personalized curricula that take learning styles into account. Such claims, whilst being very positive about the learning styles paradigm, tend to discount or downsize the impact of other aspects of pedagogy and educational strategies, and may cause more harm than good in the hands of inexperienced educators who might label and categorize students in an overly simplistic fashion.

2.2.1.4   Applications

For all the claims made by Dunn and Dunn and their supporters, tools such as the Learning Styles Questionnaire and the Learning Styles Inventory have no direct link to models of learning per se, but do have links to models regarding instructional preferences. While this is not necessarily a negative point, it is important to underline the distinction. Multiple studies support strong claims about the educational benefits of adapting pedagogical strategies and media to the learning styles of students, yet most of these studies have been conducted by supporters of the Dunn and Dunn model (see Wolf, 2002 for an example), and the lack of consistent independent review and

support makes such claims questionable. No information is available on business models and the use of the Dunn and Dunn model.

2.2.1.5   Overall assessment

Coffield et al. find Dunn and Dunn's model to show promise with respect to its ability to stimulate the educational system and individual tutors into questioning what is appropriate in terms of personalized pedagogical strategies. This model may also encourage the respect of individual differences in learning styles among learners, provide some simple and intuitive means to assess some of the students' shortcomings, and finally help to establish a common language for educators for discussing learning styles.

It should be noted that the problems may loom larger than the benefits. For example, the many references to hereditary factors, as well as the findings in neuroscience about brain lateralization and specific cognitive features are of general scope and have not received substantial support in establishing any relation with learning styles. This over-simplistic belief in the fixation of cognitive learning styles and the encouragement of the adoption of what works best for the individual, with no further questioning about other preferences and modalities is of concern. Furthermore, there is a lack of truly objective measures of learning styles and preferences, despite all claims from Dunn and Dunn's supporters. Finally, and perhaps most importantly, there is a lack of independent validation of the methodology.

2.2.2   Gregorc's Style Delineator (GSD)

2.2.2.1   Overview and design of model

Gregorc's cognitive learning style model (Gregorc, 1985) is, along with Dunn and Dunn's, one of the two models reviewed by Coffield et al. that deal with learning styles as "constitutionally fixed" features based on genetics, trait inheritance, and the interdependence of personality with cognitive processes. Gregorc's "mind styles" model is a theoretical framework to consider the cognitive processes involved in the assimilation and integration of information, along two axes or spectrums, namely perceptual qualities and ordering abilities.

The two dimensions of Gregorc's model are the concrete-abstract spectrum of perceptual quality, and the sequential-random spectrum of ordering ability. Gregorc does not conceptualize individuals as strictly using one style and neglecting others, we all have an innate predisposition which determines how information is processed. For instance, individuals with an inclination toward processing knowledge in a concrete fashion register information directly through their senses and frame the information in the current context (i.e., locally in space and time). Individuals with abstract styles conceive of ideas in an intuitive, imaginative way, visualizing and shaping information beyond the boundaries of the concrete reality around them. In terms of ordering ability, sequential individuals frame and organize knowledge in a linear, stepwise structure, following logical relationships and planning ahead to achieve their objectives. People with a more random approach to ordering information frame it in an "order-less" manner, preferring to cluster related knowledge together in chunks, tending to skip steps or reverse them in sequences of events or actions in the pursuit of their goals, and by being more impulsive than sequential types with their planning-oriented processing.

As mentioned above, perceptual and ordering features of the mind are found in all individuals, but manifest themselves in different patterns and magnitude much like personality traits. It should be noted that since Gregorc is inclined to think that cognitive styles and learning preferences are constitutional dispositions of the mind shaped by inheritance and neurobiological constraints; there are no opportunities for individuals to "change" these innate predispositions. According to Gregorc, individuals should learn to use these inclinations to their advantage and they should refrain from trying to alter their cognitive makeup.

2.2.2.2 Reliability and validity

Although Gregorc reports high consistency between his self-test "style delineator" inventory and re-tests on the same individuals, there have been no positive findings via independent evaluation on the self-test and re-test claims from Gregorc's own work. Worse still, independent reviews of the psychometric test itself found that the internal consistency and factorial validity of the categories, properties and boundaries of the modeled cognitive and learning features are flawed (Joniak & Isaksen, 1988; O'Brien, 1990; Reio & Wiswell, 2006). The GSD scales are designed in such a way that the results are exacerbated by the constructs used in the psychometric test, yet the constructs themselves do not yield conclusive results on the two-axis framework of the GSD (e.g., with factors belonging within the abstract or concrete spectrum being poorly correlated with their own category).

2.2.2.3 Implications for pedagogy and evidence of pedagogical impact

Gregorc uses his prior experience as a professor to provide evidential support for his claims of the strong relationship between individual cognitive styles and pedagogical strategies as well as instructional media preferences. He argues that a diversity of instructional media is the preferred path for instructors and learners. Very little support for the pedagogical implications of the GSD is available, with only a handful of studies found by Coffield et al. on the subject matter (Lundstrom & Martin 1986; Seidel & England 1999; Harasym, Leong, Juschka, Lucier, & Lorsheider, 1995; Drysdale, Ross, & Shulz 2001). Whereas the sequential-random distinction is supported in some of the studies in educational settings, the abstract-concrete distinction is not supported by the results

2.2.2.4 Applications

Given the scarce evidential basis for the application of the GSD, even the few articles on pedagogical impacts of the style delineator do not yield to recommendations and applications beyond the classroom. There is no reference of research on the GSD and its impact on other popular uses of cognitive learning style models such as business, professional training, and e-learning.

2.2.2.5 Overall assessment

Gregorc's model of cognitive styles and learning preferences has vague implications, is flawed on theoretical and methodological grounds, is not supported by sufficient independent reviews, and is of little scope and help for all intents and purposes of the present review.

2.2.3   Riding's Cognitive Styles Analysis (CSA)

2.2.3.1   Overview and design of model

Riding's model (Riding & Rayner, 1998) is an example of the cognitive learning styles literature that conceives learning styles as structural properties of the cognitive system itself. An underlying assumption is that cognitive styles are not particularly amenable to change, since the idea of cognitive structure implies "hardwired" and fixed traits that may not yield the flexibility of other models of learning preferences and strategies. The CSA approach defines (i) a cognitive style as the individuals' preferred and habitual approach to organizing and representing information, and (ii) a learning strategy as the processes used to respond to the demands of a learning context. Cognitive styles are stable and built-in features of the individual mind, while strategies may vary and be developed. There are two dimensions that define the cognitive styles analysis methodology: the verbalizer-imager spectrum (the dominant mental representations of individuals), and holistic - analytic axis (the cognitive organization of individuals). Those two axes are considered independent of one another (i.e., there is no correlation between their constructs and factors), and Riding emphasizes that his measures are not meant to indicate the strength of individuals' abilities along those factors, but to represent natural tendencies towards information processing.

Riding's psychometric test is thus concerned more with latencies in information processing along cognitive organization and mental representation than with accuracy ratings, in order to assess cognitive proclivities, not cognitive performance. Riding's model is offered in a computerized format, and constitutes a psychometric test of psychophysical measurements that is not transparent to the subjects undertaking the CSA. For the cognitive organization dimension (holistic - analytic axis), latencies are measured via visual tasks, a matching task for the holistic - analytic factor of preference, and an embedded figures discrimination task for the analytic factor of preference. The tasks related to the mental representation dimension (verbalizer - imager axis) are verbal tasks where latencies are measured on conceptual similarity categorization tasks (verbal preference), and on color similarity categorization tasks (visual preference). The tasks elements are simple, involving single words in each trial, and although the CSA is aimed at adults; alternatively it may be used on children without confusion.

2.2.3.2   Reliability and validity

The only evidence on the test-retest reliability of Riding's CSA has been provided by independent reviewers, and unfavorably so, by Peterson, Deary, and Austin (2003) as well as Parkinson, Mullally and Redmond (2004). These authors found not only weak test-retest correlation scores, but Parkinson et al. found negative test - retest correlation scores. Coffield et al. note that under such circumstances where reliability has not been confirmed (internally or by independent reviewers), a discussion on its constructs and factors' validity is rather pointless. Comparisons with other learning style models, such as the CSI developed by Allinson and Hayes (1990), have also suggested very weak correlations, pointing out to further unreliability along constructs, factors, and measurement robustness.

Riding's conception of mental organization and mental representation as fixated features of dominance or inclination is problematic, since Riding's tools and conceptual background assume this fixation instead of testing for it. This is opposite to Vermunt's insistence on metacognitive processes being able to override and alter learning styles (Vermunt, 1998). Coffield et al. also contradicts the rationalization that the psychometric test's simplicity leads to robustness. The reviewers are quite skeptical about the validity of an assessment of cognitive styles based on one or two tasks, using only two modalities (verbal and non-verbal), for each of merely four dimensions, and worse, using a ratio measure instead of independent quantitative scoring.

2.2.3.3 Implications for pedagogy and evidence of pedagogical impact

Riding, not unlike Dunn and Dunn's claims, considers that less apt learners could benefit greatly from the matching of educational strategies and pedagogical tools tailored to their individual cognitive styles. Riding acknowledges that other factors may be more prominent in determining performance, such as memory, attention, motivation, and so on. According to Coffield et al., based on test - retest reliability and construct or factorial validity alone, pedagogical uses of Riding's CSA should be avoided.

Riding and his colleagues did raise some interesting characterizations of educational contexts and the impact of cognitive styles (Sadler-Smith & Riding, 1999), such as the finding that holistically inclined students may favour collaborative work and non-traditional pedagogical media. However, even these results have been contested by Atkinson (1998) who found poorer performance among similarly characterized students being allowed to work in groups. There is thus no solid empirical basis for recommendations and their implementation for pedagogical purposes. Coffield et al. found no evidence in the literature on cognitive and learning styles of any impact on education and pedagogy for Riding's CSA, beyond the multiple attempts from the authors and some rare reviewers to validate the psychometric test.

2.2.3.4 Applications

Besides the above-mentioned attempt by Sadler-Smith and Riding (1999) to validate the CSA tool in an educational context, as well as an experiment conducted by Sadler-Smith, Allinson, and Hayes (2000) looking at cognitive learning styles and continuing professional development, there is no substantial evidence from theoretical and experimental reviews on the benefits of applying Riding's cognitive styles analysis method in educational and business contexts. Riding's CSA simply does not offer reliable means to assess cognitive styles, and very few, inconclusive applications can be found in the literature to support the adoption of this model.

2.2.3.5 Overall assessment

Coffield et al. claim that Riding's model, not the psychometric tool itself, may have important implications for education, as it is possible that a mismatch between a pedagogical environment and the cognitive styles of some learners may hinder their performance or simply the quality of their learning experience. Riding's, as well as some independent reviewers' research, shows some evidence of a relationship between cognitive styles and instructional preferences, yet insufficient research has been conducted to date to assess the validity and implications of such claims.

2.2.4　Apter's Motivational Style Profile (MSP)

2.2.4.1　Overview and design of model

Apter's motivational style profile (Apter, 2001) falls within the median of Coffield et al.'s spectrum between fixed cognitive factors and preferences or strategies over which individuals have more control. Thus, Apter's model is one of personality types that influence learning preferences and styles. Coffield et al. reviewed Apter's model with the understanding that it is not a model of learning styles, but that models of motivation and personality have a direct impact on learning styles and preferences, and have their place among cognitive models.

Apter's MSP is a model based on the theory of personality referred to as reversal theory. According to this theory, people are driven by motivational states that can be understood as polarized psychological needs and styles of interaction with the world (for all intent and purposes, such interactions will be qualified as cognitive styles hereafter, as they ultimately refer to emotional, motivational, cognitive, and behavioural constructs). The occurrence of a reversal, or switch between cognitive styles is conceptualized by Apter as being caused by frustration or satiation. The MSP is composed of psychometric scales and sub-scales, with spectrums made up of binary characteristics that include optimism and pessimism, seriousness and playfulness, being competitive and affectionate, having a self versus other orientation, etc.

2.2.4.2　Reliability and validity

Test - retest and internal consistency values using correlation and regression scores fall within acceptable ranges according to Apter, Mallows, and Williams (1998). Very little independent validation is available; specific variations of the motivational style profile, such as the Team Contribution System and the Work Impact System, developed by Apter for business and workplace contexts, have no references at all for validity or reliability. Coffield et al. warn that Apter's MSP tool may not do justice to the theoretical framework on which it is based, the reversal theory of motivational states, as the polar opposites that constitute dimensions of motivational styles are not found to be unequivocally opposite ends of a same spectrum. Thus, along with Allinson and Hayes' model, the psychometric measurements might benefit from being dissociated and separately assessed (e.g., measure the inclination for conformity and a taste for challenges on a different scale rather than treating them along a spectrum as opposite factors).

2.2.4.3　Implications for pedagogy and evidence of pedagogical impact

Coffield et al. envision the MSP as a tool with potential use for pedagogical ends. By taking into account aspects of personality types such as motivation, emotions, and proclivities of individuals, a model of learning can be complemented and expanded on, in a heuristic fashion, for the description and prediction of learning styles and preferences, and can be used for recommendations on pedagogical strategies and tools.

The motivational dimension of Apter's model deals with goal-oriented and activity-oriented individual proclivities. Such features of motivation may be directly related to cognitive learning style models that oppose extrinsic and intrinsic motivational features, or more concretely, map

onto learners' styles and preferences such as pursuing high academic results as opposed to learning for other purposes (an interest for the content of the subject matter), as an example..

2.2.4.4   Applications

Apter developed business management and training oriented tools for specific applications of the MSP. Two noteworthy tools are the Apter Team Contribution System (ATCS) and the Apter Work Impact System (AWIS). Unfortunately, very little information is available on such products, beyond the understanding that their purpose is to facilitate collaborative work in business environments by means of evaluation of self-perception, the perception of others, the assessment of satisfaction and values in the workplace, etc. No independent reviews are available for such MSP derivatives.

Coffield et al. are confident that motivational and personality styles features of Apter's model may play a role in pedagogy and the overall study of cognitive learning styles. Since Apter's model challenges the fixation of personality features via reversal theory and allows for a more dynamic and flexible assessment of individual styles, cognitive learning styles may benefit from the richness of motivational and personality assessments in creating a learning environment that takes into account factors such as boredom, complacency, satisfaction, etc.

2.2.4.5   Overall assessment

According to Coffield et al., the reversal theory upon which MSP is built hints that more flexibility and dynamic features can be assessed in cognitive features related to personality, motivation, and ultimately, learning. There are many benefits to adopting a mutable and dynamic point of view about learning styles, which are generally seen as fixed or resilient to change. Unfortunately, for all the potential of Apter's MSP, there is no rigorous body of research that provides insights about the impact of reversal theory or MSP on learning and pedagogy, nor on actual recommendations about the implementation of MSP-sensitive technologies and strategies. Little information is thus available to substantiate even Coffield et al.'s claims, beyond Apter's own.

2.2.5   Jackson's Learning Styles Profiler (LSP)

2.2.5.1   Overview and design of model

Jackson (2002) envisions his learning style model as a subset of personality factors, based on biological constraints and inspired by neuropsychological theories and concepts. Jackson proposes four learning styles as components of the more general personality types: the initiator, the reasoner, the analyst, and the implementer. Unlike Honey and Mumford (2000), and Kolb (1999), Jackson does not conceptualize his learning styles as dependent on a learning process or cycle; instead, they are fixed personality traits which are manifested by individuals, and each has its strengths and weaknesses.

The LSP is an inventory with 80 questions, arranged in four sets of 20 items for each learning style. Jackson's model is even offered in a computerized format with feedback scores for self-evaluation. The key characteristics of each style, along with a set of strengths and weaknesses,

allow learners to find out about their personal learning profile and the computer version even makes recommendations as to what styles to improve, as well as how to do so. Jackson's model is thus straightforwardly descriptive and prescriptive.

As a summary example, an initiator may be very spontaneous and may think very little before acting. He or she may speak before thinking, and may not consider the many advantages and disadvantages of his or her actions before making up his or her mind. Therefore, an initiator's strengths are the willingness to engage or tackle problems, having a propensity to be the centre of attention, and making things happen or getting things done. An initiator's weaknesses include a lack of attention to context before acting, a tendency toward egocentrism and a lack of focus on others, and finally, a tendency toward making mistakes or being accident-prone.

2.2.5.2   Reliability and validity

Jackson claims that three studies support the reliability and internal consistency of his model, with test-retest values falling in reasonable ranges in an experiment involving students and propfessionals. Coffield et al. note that the significance values and correlational scores for this study are only moderately encouraging, and that one type of learning style (the reasoner) fails to provide consistent test-retest scores.

A quick look at the factorial and construct validity reveals that the learning styles are expected to produce polarized values, with initiators and reasoners being somewhat negatively correlated, and reasoners and analysts being positively correlated. Coffield et al. cast some additional doubts and reservations on the accuracy of the labels of Jackson's learning styles relative to their features, judging the model's labels as poor descriptors of the underlying factors used to determine styles. For instance, Jackson's characterization of reasoner does not reflect the quality of self-efficacy that its factors appear to convey, whereas initiator does not reflect the impulsivity of the features used to elaborate this learning style. The reviewers also comment that implementer is presented negatively and appears to suggest that reflection and reasoning are opposed to practicality, whereas analyst is equated with a strong sense of organization, which is not warranted by the label.

2.2.5.3   Implications for pedagogy and evidence of pedagogical impact

Coffield et al. have observed that very little independent validation exists on the matter of the relevance, practicality, and value of the LSP. Jackson's own work is more geared towards organizational settings, and there is little to say on educational implications. The computerized model of LSP offers interesting suggestions and recommendations for personal development, a point that appeals to Coffield et al., but requires significant refinements, further reviews, and substantiation via experiments before any pedagogical commitments can be made.

2.2.5.4   Applications

Jackson's learning styles profiler is intended for use with adults, and has been standardized for use in various contexts, yet only appears to have gained popularity in business environments; particularly for the purpose of personnel selection, evaluation, professional development, the facilitation of collaborative work, and establishing landmarks for learning cultures. More recently

Siadaty and Taghiyareh (2007) attempted to provide e-learners with web-based pedagogical personalized learning content which was adapted based on students' responses to Jacksons' LSP questionnaire. Findings were inconclusive as one case of the study found differences in performance between matched and non-matched students, whereas another case of the study did not find any significant difference.

2.2.5.5   Overall assessment

The LSP, whilst designed with business and education in mind, requires further refinement and evaluation. The creation of a computerized model of the learning styles inventory and questionnaire is a promising feature, as is the idea of elaborate and personalized feedback for prescriptive measures based on individual learners' answers. While Jackson's model is a relatively recent one and thus no one could expect a wealth of applications and reviews, there are nevertheless significant issues associated with the design of the psychometric tool's constructs themselves. The learning styles described by Jackson have been found to be poor descriptors of the factors on which they are built (Coffield et al.), and until further developments are made, the model cannot be recommended for serious or in-depth use.

2.2.6   Myers-Briggs Type Indicator (MBTI)

2.2.6.1   Overview and design of model

Myers and Briggs' model (Myers & McCaulley, 1985) is, along with Apter's and Jackson's models, more about personality than learning styles. The MBTI inventory is very popular and in widespread use, as Coffield et al. found that more than 2000 articles have been published about the instrument and a reported two million copies of the MBTI are sold every year. The MBTI is based on four bipolar dichotomies representing stable personality types: extraversion-introversion, sensing-intuition, thinking-feeling, and judging-perceiving. A matrix of all possible combinations thus generates sixteen possible personality types, and each type has positive and negative traits associated with it.

The MBTI instrument consists of forced-choice questions based on the abovementioned four bipolar dichotomies, and has received many revisions, with the most recent inventories being composed of 93 items and 126 items (1985 and 1998, respectively). Coffield et al. emphasize the sheer complexity of the MBTI inventory, with the sixteen personality types involving sets of relationships among the functions (sensing, intuition, thinking, feeling), attitudes (extraversion and introversion), and relationship with the world (judging and perceiving). The MBTI involves many aspects of personality and behaviour not directly related to learning, but learning does have an important role within the conceptual framework of personality types and may inform the learning styles literature.

2.2.6.2   Reliability and validity

The validity of the bimodal constructs in the type indicator's four scales (i.e., extraversion - introversion, sensing - intuition, thinking - feeling, and judging - perceiving) has been the focus of considerable attention in the research community, as the tool's polar opposites have not been

supported by external reviews, and some contradictory support has even been documented in the form of high scores for the allegedly polar opposites when separated into multiple factors (Hicks, 1984; McCrae & Costa, 1989; Girelli & Stake, 1993; Bess & Harvey, 2002). According to the critics, the scores generated by the standard MBTI are artifacts of the forced-choice design and the polarized scales, and will consistently generate data that is meant to fit the theoretical background, no matter what the reality of the constructs might be.

The authors of the MBTI report test - retest reliability values that are acceptable (Myers & McCaulley, 1985), but the factorial design appears more consistent than the whole-type stability, the latter being (unfortunately) the precise objective of the MBTI according to Myers and McCaulley. One of the test - retest reliability issues is that the force-choices design of the MBTI is so sensitive to small numerical differences, that a slight change in median scores along any dimension can tip the result into the opposite characterization (Howes & Carskadon, 1979).

Coffield et al. caution their audience that the bulk of the literature about Myers and Briggs' MBTI comes from materials published *by their advocates and colleagues*. Therefore, some independent reviews are quite skeptical of the neutrality required to evaluate the psychometric tools from Myers and Brigg's advocates (Pittenger, 1993; Mastrangelo, 2001).

2.2.6.3   Implications for pedagogy and evidence of pedagogical impact

There is limited evidence pointing toward the value of matching learning styles between learners and tutors, as can be seen with many other learning style models in the present document. Advocates of the MBTI such as Van (1992) claim that style matching may improve achievement and retention rates of students, and the MBTI should thus be considered as a serious tool for the implementation of sophisticated pedagogical strategies taking into account personality types and learning styles. Alternately, the study of Spence and Tsai (1997) has found no evidence of matching MBTI personality types with dominant learning methodologies; whereas Di Tiberio (1996) comments that there is no empirical evidence about the MBTI that indicates an increase in performance or satisfaction relative to personality type matching between learners and tutors.

Predicting learning outcomes via the use of the MBTI inventory is inconsistent and unreliable according to Coffield et al. They based on their conclusions on the work of Thorne and Gough (1999) who examined a decade's worth of MBTI data. Thorne and Gough only documented moderate correlations between certain personality types and academic results.

2.2.6.4   Applications

The MBTI has been used in academic, professional, and business contexts, to profile personality types, help with career and training management, suggest career paths, and to assess personality and the likelihood of competence and satisfaction of individuals within the context of the workplace. Coffield et al. are disquiet about the use of the MBTI to test people already within a profession or within particular learning environments, for it clearly obfuscates the impact of other factors such as the culture of the work environment, the community of practice, gender differences, and other social, cultural, and ethnographic factors in student samples from higher education institutions, for example.

2.2.6.5 Overall assessment

The MBTI has a broad scope that does not yield many rigorous observations about educational implications of learning styles, being concerned with a larger framework of personality types and traits. The personality types revealed by the Myers and Briggs' inventory do not predict performance, nor do they unequivocally exhibit any benefit from learning style matching between learners and tutors, or learners and the learning environment. The relation between the MBTI and educational strategies or pedagogical tools is therefore inconclusive and unsubstantiated. The use of the psychometric test by institutions with the intent of assessing the adequacy or likelihood of performance of individuals is once again ill-recommended, as the rationale of the personality type indicator was not to stereotype or pigeonhole individuals to fit them into a specific mould, nor was there any evidence that the factors of the personality types were immutable.

2.2.7 Allinson and Hayes' Cognitive Styles Index (CSI)

2.2.7.1 Overview and design of model

The CSI of Allinson and Hayes (1996) sees the continuum of intuition and analysis as the most fundamental characteristic of cognitive styles. Unlike the models of Dunn and Dunn (Dunn & Griggs, 2003), Gregorc (1985), or Riding (Riding & Rayner, 1998), Allinson and Hayes' model is not aimed at the level of constitutionally-fixated features of cognition, or modality-based criteria, but falls along the analysis of learning styles as complex features dependent on factors such as motivation, environmental features, educational culture, etc. Thus, Coffield et al. treat Allinson and Hayes' model of learning styles as a stable yet flexible set of learning preferences that vary from individual to individual based on cognition and the aforementioned factors.

The CSI was developed by Allinson and Hayes as a psychometric test for research in organizational contexts. The intuition-analysis dimension of cognitive styles that is the foundation of the CSI is measured via a 38 item inventory which measures an individual's propensity to act intuitively or analytically through general statements, to which the participant must answer positively or negatively (with another alternative being uncertain about the statements).

In Allinson and Hayes' view, intuition and analyticity are characteristics of right or left brain dominance in cognitive processes. Intuition is generally associated with right brain dominance, as it involves immediate judgment that is based on feelings and emotions and is generally correlated with a holistic understanding of knowledge and events. In contrast, analysis is typically associated with left brain dominance, as it involves rational and logical judgment, with a focus on minutiae.

2.2.7.2 Reliability and validity

The CSI tool has been supported by the authors (Allinson & Hayes, 1996; Allinson, Chell, & Hayes, 2000) with strong claims on internal consistency and test - retest reliability, which multiple external reviewers have supported (Murphy, Kelleher, Doucette, & Young, 1998, Sadler-Smith, Spicer, & Tsang, 2000, Löfström, 2002). In addition to positive reviews on internal reliability, many correlations have been established with the learning style models of other authors, such as Honey and Mumford's LSQ (Section **2.2.9**), Myers-Briggs' MBTI (Section

2.2.6), and Entwistle's ASSIST model (Section **2.2.11**). One important criticism from Hodgkinson and Sadler-Smith (2003) shows however that there is evidence that intuition and analysis should not be considered opposites, but negatively correlated features, and thus should be measured as two separate factors within the psychometric test.

2.2.7.3 Implications for pedagogy and evidence of pedagogical impact

Allinson and Hayes derived an interesting principle called the matching hypothesis (Allinson, Armstrong, & Hayes, 2001), whereby individuals with similar cognitive styles have been demonstrated to perform better when matched with others of similar learning style in collaborative learning for business training or education. The impressive number of remarks made by Coffield et al. on reviews of Allinson and Hayes' CSI model are very insightful but ultimately context-dependent. Furthermore, findings from secondary literature come across as interpretations and speculations as opposed to direct, evidence-based assertions. The CSI model has generated a lot of support in the business training domain, but pedagogical impacts have not yet been investigated thoroughly.

2.2.7.4 Applications

Most of the studies on the CSI have been conducted in business training contexts, precisely in line with the original intent behind the CSI. Across multiple studies involving business training within corporations and enterprises, as well as in business education programs in academia, the CSI has been used to assess cognitive styles and preferences, as well as the compatibility between mentors and students. The main problem of the application of the CSI in business training contexts may lie in its unequivocal interpretations on what the data yields, as some confounded factors may play a significant role in the assessment of the intuitive and analytic qualities of mentors and learners. Examples of such confounds include the amount of experience, work environment, cultural imperatives, gender, individual performance, and intellectual abilities. Thus, well-controlled empirical studies are required to validate CSI-based claims.

2.2.7.5 Overall assessment

Allinson and Hayes' model could be made more efficient if it were reconceptualised as a two-factor model instead of its current single-dimension psychometric tool (Krueger & Kickul, 2006). The model has been supported with robust evidence for reliability and validity, from the authors, external reviewers and researchers. One issue open to discussion is the over simplistic notion of brain lateralization and its consequences for cognitive processes for individual characterization of learning styles. In the hands of unwary individuals, this over-generalized dichotomy of left versus right brain dominance as based on unequivocal neuroscience research, could be misused and ultimately unhelpful. Importantly, the CSI's spectrum of analysis and intuition has been proven to have heuristic value in research on decision making and performance in many business environments, yet very little has been done on its pedagogical implications and its application to educational settings.

2.2.8 Herrmann's Brain Dominance Instrument (HBDI) overview and design of model

2.2.8.1 Overview and design of model

Herrmann's brain dominance instrument (Herrmann, 1989) is classified by Coffield et al. as resting within the median of the spectrum of fixated and modality-dependent cognitive styles, and contextual and flexible learning approaches and strategies. Along with Allinson and Hayes's CSI (Section **2.2.7**), Honey and Mumford's LSQ (Section **2.2.9**), and Kolb's LSI (Section **2.2.10**), Herrmann's model thus falls within the family of stable yet flexible learning preferences. The HBDI is a psychometric inventory that focuses on "mental preferences", or thinking styles, supported by data provided via electroencephalography and inspired by the brain lateralization paradigm in cognitive neuroscience.

The HBDI is a self-report test composed of 120 questions rated along four categories that can be understood as "cerebral-left" or rational self (also referred to as theorist type), "limbic-left" or safe-keeping self (organizer type), "cerebral-right" or experimental self (innovator type), and the "limbic-right" or feeling self (the humanitarian type). It is postulated that individuals who manifest traits of a category will have difficulties in relating to opposite types, (e.g., a theorist or cerebral and left dominant type would find it difficult to relate to limbic and right dominant types, or humanitarians).

Over time, however, Herrmann has shifted toward a more liberal interpretation of these categories, which are more akin to metaphors, as lateralization has come to be perceived as an oversimplification of empirical findings on hemispherical and anatomical functions in cognitive processes within the cognitive neuroscience literature. The more recent "whole-brain" metaphor is more flexible and Hermann's view has shifted towards the conception of brain dominance in learning preferences. The model's categories have been modified to accommodate this more contemporary conception of whole-brain dominance, with a quadratic topology composed of "upper-left" to "lower-right", instead of the old cerebral versus limbic taxonomy.

2.2.8.2 Reliability and validity

There are unfortunately very few independent reviews of Herrmann's HBDI, and Coffield et al. can only commit themselves to some coarse-level judgment on the apparent factorial and construct validity of the HBDI, but even the scarce number of reviews on the matter are from individuals contracted by, or related to, Herrmann and his colleagues. Indications of test-retest reliability are only available from Herrmann and colleagues (Herrmann, 1989) as well. The model's constructs and factorial elements are correlated positively with a number of other learning style models, such as Myers-Briggs's MBTI, Kolb's LSI.

2.2.8.3 Implications for pedagogy and evidence of pedagogical impact

Herrmann's recommendations for education and pedagogy fall along the lines of the many other learning style theorists presented in this review. He suggests that the proper diagnosis of student learning preferences, and the adequate matching of the learning environment and tutors'

pedagogical style with such learning preferences, are the key to facilitating education and improving student performance and satisfaction.

Promoting collaborative work that combines different learning styles and preferences could facilitate the understanding of individual differences in learning and may prepare students for different workplace realities, where divergent learning preferences would normally hinder their performance or satisfaction.

2.2.8.4 Applications

An interesting study by Herrmann (1996) substantiated claims that major differences have been found in correlational studies on brain dominance, learning preferences, and occupational groups. According to Herrmann, HBDI profiles compiled in a database of 113,000 cases demonstrated some strong correlations between brain dominance and occupation, such as profile Type A (rational) with careers in engineering, actuarial sciences, Type B (safe-keeping) with assembly line workers and bank clerks, Type C (feeling) with nursing, elementary school educators, and Type D (experimental) with artists and entrepreneurs.

Herrmann's model has been very popular in the business world, where it has been applied to promote individual creative potential and to facilitate collaborative work between individuals with different learning preferences, thus facilitating greater synergy between coworkers (Herrmann, 1996, Martin, 1994). Herrmann (2007) believes that by understanding your own learning style and the learning styles of your workers, communication, efficiency, and productivity will increase. Applications within the context of education are not significant and more independent validation is required.

2.2.8.5 Overall assessment

Herrmann's' HBDI relies on a well-established legacy of experimental research carried over many decades, and the combination of simplicity and transparency of its constructs and commitments is a strong selling point. However, in line with other models of learning styles reviewed by Coffield et al., over-simplistic models relying on a small set of criteria are as prone to misinterpretation as are more complex models. It is important to resist the temptation to generalize and stereotype individuals through labels and caricature categories. Herrmann (1996) acknowledges that flexibility and growth are more important in the assessment of learners' styles and preferences, than is a taxonomy of characters. Ultimately, the HBDI is merely a tool, but the learning process is far more important and the tool should not determine the experience and development of individuals. To conclude, some of the beneficial features of Herrmann's model are its independence from cognitive ability, its reliability, and its transparency, but its main shortcoming is the lack of substantiated support, both from the authors and external reviewers, for pedagogical ends and educational needs.

2.2.9 Honey and Mumford's Learning Styles Questionnaire (LSQ)

2.2.9.1 Overview and design of model

Honey and Mumford's LSQ (Honey & Mumford, 2000) defines a learning style as the set of attitudes and behaviours that determines an individual's preferences. Along with Allinson and Hayes' CSI (Section 2.2.7), Hermann's HBDI (Section 2.2.8), and Kolb's LSI (Section 2.2.10), Honey and Mumford thus view learning styles as stable yet flexible learning preferences (Coffield et al.). The four learning styles, or archetypes of learning preferences, are dubbed by Honey and Mumford as activists, reflectors, theorists and pragmatists. Each learning style is conceived as a general pattern of aptitudes and predispositions. Importantly, each style also has its own characteristic strengths and weaknesses, thus one cannot establish a hierarchy of styles from better to worse.

The LSQ consists of 80 items, broken down in four blocks of 20 questions, with each block matching the four learning styles mentioned above. Honey and Mumford deliberately organized the LSQ to be clear and highly simplistic, with binary answers, and an emphasis on flexibility. They warn potential users against the use of their psychometric tool for personnel selection or competency assessment. Indeed, Coffield et al. offer the same warning about the assumptions of authors in the learning styles literature on the benefits of oversimplification in categories and constructs, as inadequately trained users might not see the implications and implicit assumptions underlying the models' characteristics, with the potential for mislabeling or stereotyping individuals through unwarranted inferences.

Honey and Mumford thus view their psychometric tool in a strictly pragmatic way, aimed at providing comprehensive feedback to tutors, trainers, and learners about their strengths and weaknesses given certain inclinations to one learning style or another. The goal is improvement, not assessment or labelling, and learning preferences are seen as mutable, shaped by experience, meaning that they can be co-opted and refined.

2.2.9.2 Reliability and validity

An important number of independent reviewers have suggested that the LSQ suffers from a lack of predictive value and construct validity (Furnham, 1992; Furnham, Jackson, & Miller, 1999: Jackson & Lawty-Jones, 1996), whereas more positive reviews can be found from Allinson and Hayes (1990) on internal consistency, and from the authors themselves (Honey & Mumford, 2000) on test-retest validity. Yet other reviewers shed an unfavorable light on the LSQ, having tested its factorial validity (Swailes & Senior, 1999; Sadler-Smith, 2001) and internal consistency (Duff & Duffy, 2002) with poor results. The authors have replied to the academic reviewers by invoking that the LSQ was not created as a psychometric tool, nor as a tool for individual personality assessment, but as a straightforward self-diagnostic tool with no pretention of sophistication or thorough scientific value (Honey, 2002).

2.2.9.3 Implications for pedagogy and evidence of pedagogical impact

There have been virtually no studies on the pedagogical impact of Honey and Mumford's LSQ, as the model has been generally used in the business environment. However, Coffield et al. agree

with some potential benefits mentioned by Honey and Mumford for workplace training and management; in designing personal development plans and being more sensitive to individual learners' strengths and weaknesses.

2.2.9.4 Applications

The lack of robustness and consistency of the LSQ may have hindered its deployment and use in educational contexts, and Honey and Mumford's model ultimately remains a pragmatically-geared tool for self-development. Surprisingly, numerous references were found on Honey and Mumford's learning style model for e-learning applications (De Bra, Aerts, Berden, de Lange, Rousseau, Santic, Smits, & Stash, 2003; Grigoriadou, Papnikolaou, Kornilakis, & Magoulas, 2001; Papanikolaou, Grigoriadou, Kornilakis, & Magoulas, 2003; Stash, Cristea, & De Bra, 2004). This is a rare occurrence in the technology-oriented literature about distance education. The studies by Grigoriadou et al. (2001) and Papanikolaou et al. (2003) present a system architecture for adaptive educational hypermedia system (INSPIRE). INSPIRE is an intelligent tutoring system that dynamically generates lessons based on learners' goals, knowledge level, and learning style. By using Honey and Mumford's learning styles questionnaire in a preliminary assessment phase, Grigoriadou and his colleagues implemented more flexible hypermedia features in their intelligent and adaptive tutoring system.

2.2.9.5 Overall assessment

The LSQ aims to identify attitudes and behaviours that constitute the basis for learning preferences. Honey and Mumford admit to its simplistic value, and do not commit their tool to the rigors of psychometric instrumentation. Coffield et al. underline the danger of labelling individuals as possessing one style or another, without considering possible combinations of more than one preference. The LSQ has been assessed as exhibiting poor predictive value of performance and preferences, and thus cannot be recommended for its lack of reliability and validation. Honey and Mumford's LSQ has been compared throughout all independent reviews to Kolb's model, from which it is inspired, and is considered to be a poor alternative to an already flawed model (Section **2.2.10**).

2.2.10 Kolb's Learning Style Inventory (LSI)

2.2.10.1 Overview and design of model

Kolb's learning style inventory (Kolb, 1999) is a psychometric tool based on his theory of experiential learning (Kolb & Fry, 1975), which is based on the assumption that learning is the creation of knowledge as a product of experience and of the transformation of this experience into useful information. Kolb envisions the learning process as a four-step cycle, and these four steps include concrete experience, reflective observation, the formation of abstract concepts as based upon reflection, and active experimentation.

From his characterization of learning stages, Kolb derives four types of learning styles, seen as flexible yet stable tendencies naturally evolved in individuals to deal with their environment. The resulting four types of learners are the converger (favouring active experimentation and abstract

conceptualization), the accommodator (favouring active experimentation and concrete experience), the assimilator (preferring reflective observation and abstract conceptualization), and finally, the diverger (reflective observation and concrete experience).

The more recent version of the LSI (Kolb, 1999) consists of a forced-choice ranking tool to assess learners on their preferred learning style (i.e,. AC (abstract - conceptualization), CE (concrete – experience), AE (abstract – experience), or RO (reflective – observation). Individuals are required to complete sentences about their learning preferences based on four suggested endings that refer to the four learning styles. The individuals are then asked to rate their own assessment of the qualitative judgments made by the sentences on a four-point scale. Kolb warns against using the LSI for personnel selection or evaluation, as it is meant to be a simple tool geared towards self-evaluation of an individual's preferred way to learn. Therefore, the LSI is meant to inform the learner about his or her own style, with accompanying features, characteristics, strengths and weaknesses. Using the LSI in order to assess learning styles in organizational contexts may lead to misinterpretation or misuse, such as stereotyping and labelling individuals according to a fixed-trait model which is not what the LSI is about.

2.2.10.2   Reliability and validity

Considering its long history, Kolb's experiential learning model of learning styles has been subjected to a wealth of reviews, many of which point to a lack of reliability and validity of the LSI. Since most of the reviews provided by Coffield et al. are concerned with previous versions of the LSI, namely the 1975 and 1984 versions, the present review cannot focus on Kolb's most recent LSI – the third version created in 1999.

Test - retest reliability has been an ongoing issue over the three decades of experimentation and reviewing, with a faction providing evidence against the former LSI's reliability (Wilson, 1986; Veres, Sims & Shake, 1987; Cornwell, Manfredo & Dunlap, 1991; Newstead, 1992; Lam, 1997), and some testifying to its reliability (Kayes, 2005; Marshall & Merritt, 1986; Heffler, 2001). Coffield et al. warn against a clear-cut judgment on the issue, as yet other reviewers have obtained mixed results (Geiger & Pinto, 1991, 1992; Ruble & Stout, 1992; Loo, 1997). Therefore, the reliability of the LSI is still unclear, but on a positive note, Kolb's LSI takes into account several of the shortcomings mentioned by his critics (particularly Veres, Sims & Locklear, 1991) on means of improving test - retest reliability through the implementation of stricter methodological features.

On the issue of construct validity, Kolb has been the target of equally stringent criticism (De Ciantis & Kirston, 1996; Wierstra & de Jong, 2002) about the unrelatedness of some of the constructs used in his LSI, such as cognitive styles, learning competence, and the stages of the learning process itself. According to De Ciantis and Kirston (1996), the learning styles suggested by Kolb can be used at any of the so-called stages of the learning process, and Kolb conflates too many factors in both his model and methodology. The reviewers are skeptical with the polarization of learning characteristics on two axes, as factorial analysis may yield different results than Kolb's in different experimental settings, but also in relation to other learning styles inventories, such as Honey and Mumford's.

2.2.10.3 Implications for pedagogy and evidence of pedagogical impact

Kolb is very straightforward in his evaluation of the potential of his model for pedagogy and education, claiming that the weakness of the state of the art in pedagogy is an inability to recognize individual differences in learning styles and preferences, factors that could significantly improve the learning experience for all involved parties. The diversification of learning tools and strategies could improve learners' performance in an environment that recognizes the shortcomings of a traditional and strict pedagogical regime of unidirectional lectures, very little collaboration between learners, and minimal communication between learners and tutors. By sharing ideas and feelings about learning styles and preferences directly within the learning environment, learners and tutors could potentially tailor the modalities and content of subject matters for the specific needs of individuals or the cohort as a whole.

The empirical validation of pedagogical claims from Kolb have not met much positive reviewing, beyond the point of establishing general guidelines for learning styles-oriented pedagogical considerations (Sugarman, 1985). For instance, McNeal and Dwyer (1999) have tested the LSI on three groups of nurses randomly assigned to learning styles - sensitive instruction, learning styles incompatible instruction, and a control group with no consideration for learning styles, and found that there were no significant differences in achievement between groups. Another study by Buch and Bartley (2002) tested employees of a large financial institution with the LSI and assigned them to groups where they were trained using a variety of learning tools and strategies, some of which were learning styles sensitive or hypothesized to be incompatible, and ultimately found that the majority of learners preferred the more conservative approach of a traditional classroom with lectures.

2.2.10.4 Applications

The LSI has been used both within business and educational contexts throughout the many years since its inception and via three different instantiations, yet the reviews about its merits and flaws are inconsistent and thus leave too much to speculation. On an interesting side note, a study has been made for distance-learning involving Kolb's learning style model by Whitehurst, Powell, and Izatt (1998), presenting the DANDIE system, or Dynamic Asynchronous Networked Delivery of Individualized Education. While the distance-based learning system is merely at a prototype stage and no implementation and experimental data were presented, it constitutes a sliver of hope for further work on e-learning involving learning style models.

2.2.10.5 Overall assessment

Coffield et al. are quite dissatisfied with the bulky yet inconclusive number of reviews on Kolb's already well-established model of learning styles. Notwithstanding all of the detailed theoretical background underlying the LSI, the many versions of the LSI itself aimed at more precision, and a legacy of comments, criticism and evaluations throughout the years, it remains to be seen whether Kolb's model can or will eventually achieve reliability and validity. The experiential theory of learning is rich in detail and depth, as it has achieved a well-deserved popularity, yet the psychometric tools derived from it remain questionable on all fronts, from test - retest reliability, to predictive value, factorial design and construct validity, as well as potential impacts in various learning environments.

2.2.11 Entwistle's Approaches and Study Skills Inventory for Students (ASSIST)

2.2.11.1 Overview and design of model

The ASSIST model developed by Entwistle (1998) is part of a different paradigm on learning styles that views such features of the mind and behaviour as strategies, preferences, and approaches in the learning experience, from a holistic and flexible perspective, with factors influencing learning strategies that are as varied as previous experiences, contextual effects, and educational culture. According to Mockford & Denton (1998), Entwistle's model distinguishes three styles strongly related to students' intentions, each of which can be dominant:

- *Deep learning*, which is based on pursuing new ideas and materials through a variety of strategies in the search for understanding,

- *Surface apathetic*, where students put in a minimal effort and focus on assessment requirements, and

- *Deep, non-apathetic (strategic)*, where students focus on the product of learning rather than the process and the achievement of high grades.

For Entwistle, learning strategies are the specific and contextualized ways of information acquisition that individuals adopt in a learning environment, as relative to task demands. Thus, along with Sternberg (1999) (Section **2.2.12**) and Vermunt (1998) (Section **2.2.13**), Entwistle falls on the other end of the spectrum from Dunn and Dunn (Dunn and Griggs, 2003), Gregorc (1985), and Riding (Riding & Raynor, 1998), in that his model does not conceive learning styles as constitutionally fixated, modality-dependent, and immutable features of the mind.

Entwistle's learning strategy model and psychometric toolset is both a conceptual model and a set of quantitative and qualitative assessment tools that aim to evaluate learners' strategies and approaches to learning tasks, as well as their level of intellectual development, the level of knowledge on particular subject matter, and attitudes that learners adopt within the educational context. Entwistle is interested in students' approaches to learning, which shape their orientations and conceptions of learning, as well as the types of subject domains they are likely to be interested in, and finally, the impact of their motivations on the learning experience itself.

As based on previous research in educational psychology, Entwistle is dissatisfied with the seemingly conflicting view that while learners exhibit consistent approaches and strategies in some experimental settings (Pask, 1976), other studies emphasize the variability and adaptability of students relative to task demands (Marton & Säljö, 1976). The complex theoretical background and the depth of Entwistle's learning styles inventory address a wide array of questions such as: a learner's conception of learning (what is learning about for the student?), approaches to studying (a characterization in terms of deep, surface, or strategic approaches to learning), and student preferences with regard to pedagogical orientation (such as questions on whether individuals prefer open-ended examinations or strict and rigidly structured evaluations).

2.2.11.2 Reliability and validity

According to Coffield et al., more than 100 studies have been conducted in order to assess the many variations of Entwistle's ASSIST model, with concerns about the direct impact and implications of the ASSIST methodology in higher education. Such studies, conducted by the author and colleagues from Lancaster University and the University of Edinburgh, aimed to specify and elaborate the rationale and motivation underlying the pursuit of inquiry on learning approaches and strategies, as well as improving the reliability and validity of the many inventories used to conduct such research.

The reviews of Duff (1997), Richardson (1992), and Kember and Gow (1990) suggest that former inventories developed by Entwistle and colleagues, such as the ASI (Approaches to Studying Inventory) and RASI (Revised Approaches to Studying Inventory) demonstrate construct validity (particularly the distinction between deep, surface, and strategic approaches to learning) and internal consistency for the inventories. The scale has been investigated for validity across cultures as well. A Norwegian version of ASSIST was found to be valuable as a research tool for the assessment of approaches to learning, but authors do suggest that caution should be taken with respect to the interpretation of particular subscales (Diseth, 2001).

Unfortunately, the more recent ASSIST model and tools have not yet received sufficient attention to produce independent reviews. On a more negative note, reviews by Richardson (1992) and Sadler-Smith (1999) have found some issues with respect to the reliability of the psychometric sub-scales (i.e., between factors of higher level constructs), and test - retest reliability has not been demonstrated. The former models, ASI and RASI, have also been challenged on grounds of weak predictive validity and a bias towards certain learning approaches and strategies that may obfuscate the heuristic value of other approaches. As an example, the so-called "deep" approach to learning appears to be favoured by the authors, but one can think of the utility of surface and strategic learning approaches in different contexts (Coffield et al.).

2.2.11.3 Implications for pedagogy and evidence of pedagogical impact

Since the emphasis of Entwistle's efforts was to chart and produce a body of knowledge on the learning approaches and strategies of students (and tutors) in higher education settings, more direct implications for pedagogy can be synthesized from this particular model. In the context of higher education in the UK, Entwistle's models have been adopted as training tools for future generations of professors and teachers, to inform educators on means of improving the learning environment according to individual differences in learning preferences among their students.

2.2.11.4 Applications

The learning style models of Entwistle and Vermunt have the benefit of having been developed specifically for higher education use. Unfortunately, as Coffield et al. have suggested, there appears to be a significant gap between the information that can be obtained via the ASSIST model about learners on the one hand, and the potential recommendations for redesigning the educational workspace and pedagogical tools on the other. Furthermore, there are no apparent suggestions on the potential uses of Entwistle's model for other types of workplaces or distance learning education.

2.2.11.5   Overall assessment

Entwistle's model of learning approaches and strategies focuses on higher education, and the complexity and depth of the model's theoretical background and the available methodologies have been well-reviewed in the context of education and pedagogy. Unfortunately, such complexity also makes the model somewhat inaccessible without thorough training and first-hand knowledge. With respect to the potential misuses by unqualified personnel, Entwistle's model should not be simplified or trivialized to make hasty design recommendations for the purpose of improving pedagogical tools and strategies. The shift from learning styles to learning approaches and strategies is in itself indicative of the flexible, dynamic, and holistic character of the model, and as such very little can be isolated from a complex "model of everything" to fit more narrow preoccupations such as the design and implementation of learning technologies.

2.2.12   Sternberg's Thinking Styles Inventory (TSI)

2.2.12.1   Overview and design of model

Sternberg's theory of mental self-government (Sternberg, 1999) is the foundation of his thinking styles inventory tool. The theory links learning styles with pedagogy in a very explicit way, as compared to other reviews in the present document, and Sternberg makes strong claims about the potential of his thinking styles model to improve learners' performance. Sternberg envisions learning styles more as preferences in the use of our individual abilities, and therefore prefers the use of the term *thinking profile* rather than style. The theory of mental self-government on which the thinking styles inventory is built assumes that our actual social conceptions of government types are extensions of a similar taxonomy for cognitive and learning profiles.

According to Sternberg, there are three levels of mental self-government, corresponding to: (i) functions of governments of the mind, (ii) forms of mental self-government, and (iii) stylistic preferences. Importantly, Sternberg does not think that cognitive style characteristics are constitutionally fixated and immutable; rather the thinking styles may change according to context and experience, as well as social factors.

Sternberg's TSI is composed of 13 inventories made up of 8 items each, with a self-assessment scale for such items of one to seven. In addition to the TSI, Sternberg's tools have three other components, the Thinking Styles Tasks for Students, aimed at assessing self-reported performance rather than preferences, the Thinking Styles Questionnaire for Teachers, to profile the teaching styles used in learning environments, and the Student's Thinking Styles Evaluated by Teachers, to which Coffield et al. could not find any substantial references.

2.2.12.2   Reliability and validity

Unsurprisingly, very little information is available from the author and colleagues about the reliability and validity of the TSI, with modest claims about internal consistency. Sternberg also makes claims about external validity (i.e., Section 2.2.6 the correlation of constructs and factors with other learning style models, such as the MBTI (Section **2.2.6**) and Gregorc's Style Delineator (Zhang & Sternberg, 2001)).

There are a few serious independent reviews, such as that of Porter (2003), who tested the TSI on 150 students at a British university, and found that feedback from students indicated an interest in the educational applications of Sternberg's mental self-government theory, whilst the TSI tool itself was deemed too long, laborious, and boring. Demetriou and Kazi (2001) also observed that Sternberg's TSI results differed significantly from theirs, with disappointing scores on the relation between learning styles and performance, which they attributed to too many confounds in Sternberg's constructs (e.g., conflates features of personality and cognition).

Coffield et al. also criticize the lack of context for the inventory's items, which are general statements about thinking styles completely abstracted out of any task context. According to the reviewers, such psychometric items are poor candidates because the adequacy of a factor in any of Sternberg's thinking styles could vary between task types, or because of external circumstances. It is also observed that some of the TSI items allow individuals to fake outcomes should they want to answer in a way that presents them in a favourable light.

2.2.12.3 Implications for pedagogy and evidence of pedagogical impact

Coffield et al. assert that Sternberg's model does suggest positive implications for pedagogy: it is preferable to diversify pedagogical tools and strategies in a learning environment to better address students' various thinking styles; tutors should be aware of their own preferences in order to compensate for their biases when confronted with students who are not "matched" with them in terms of thinking styles; and finally, education and pedagogy should have well-established curricula that integrate sensitivity to learning styles. The main problem, in line with the many other models presented in this document, is the lack of empirical evidence to support claims about the relationship between the pedagogical sensitivity to learning styles and an increase in performance, motivation, or satisfaction.

2.2.12.4 Applications

Sternberg is convinced that his model is beneficial to the field of education and pedagogy, as he sees the goal of tutors is to accommodate students' thinking and learning styles, and develop pedagogical tools, methodologies, and strategies for their education and assessment. The problem lies in educators not being aware or sensitive to their own thinking styles and the various ways they are biased towards the different thinking and learning profiles of their students. The lack of independent reviews and solid empirical support unfortunately does little to assess the pedagogical potential of Sternberg's mental self-government model and his thinking styles inventory.

2.2.12.5 Overall assessment

Coffield et al.'s (2004a, 2004b) final judgment on Sternberg's model and tool is rather critical, as they mention that the addition of yet another learning style model with very little support for reliability, validity, and potential applications is quite unnecessary. Sternberg's model is indeed vague and decontextualized, its multitude of profiles is based on questionable choices (why include certain "forms" of mental self-governments such as monarchic, but discard democratic or dictatorial?). Many features of the constructs and the psychometric inventory provide a strange

metaphorical texture to the model of mental self-government, and appear to be generated out of rationalization rather than through observation and experimentation.

2.2.13   Vermunt's Inventory of Learning Styles (ILS)

2.2.13.1   Overview and design of model

The ILS model of Vermunt (1998) defines learning styles as a coherent and holistic process of learning activities that students manifest, and therefore, a learning style is the same as an approach to learning for Vermunt. This definition is far from the fixated and modality-constrained cognitive styles of Dunn and Dunn (Section **2.2.1**), Gregorc (Section **2.2.2**), or Riding (Section **2.2.3**). Instead, it is flexible and focuses on metacognitive knowledge and self-regulative means of learning. Beyond cognitive factors of knowledge processing, Vermunt's approaches to learning also include motivation, involvement, and emotions.

Vermunt defines four learning styles, or approaches to learning: meaning-directed, application-directed, reproduction-directed, and undirected learning styles. Each learning style possesses five features: cognitive processing (what an individual does), learning orientation (why we do it), affective processes (our feelings about what we do), mental models of learning (our views of learning itself), and the regulation of learning (what type of control and management of the learning do we have). The resulting matrix of learning styles and their factors is envisioned by Vermunt with considerable flexibility, with no pretention over the interdependence or mutual exclusion of such factors.

The inventory of learning styles is composed of 120 items for self-assessment, and uses a five-point scale for individual ratings. Each factor (e.g., cognitive processing, etc.) of the learning styles is further decomposed into sub-scales, which form the basic architecture of the ILS.

2.2.13.2   Reliability and validity

Vermunt himself provides sound statistical measures to support his inventory, from general construct validity to the consistency of factor analysis, with the acknowledged (and assumed) cases of overlap between certain constructs and factors. Independent reviewers such as Boyle, Duffy, and Dunleavy (2003) found that three out of four scales (using a short form of the ILS) exhibited satisfactory internal consistency, whilst a fourth (learning orientation) produced only moderate, yet still acceptable consistency along constructs. They did find poorer reliability among the twenty subscales of Vermunt's ILS. Coffield et al. caution that the predictive value for performance has no support outside of Vermunt's work, with only rare reviews hinting at poor effect sizes (Busato, Prins, Elshout, & Hamaker, 2000; Boyle, Duffy, & Dunleavy, 2003). One point of interest mentioned by Coffield et al. is that test - retest reliability scores show variability between chance levels and robust effects, yet this does not play against the theoretical assumptions of Vermunt's model, as he not only acknowledges that students have flexible approaches to learning, the model is actually based on the idea of mutable and adaptive learning styles. Thus, test - retest results are *not* expected to yield similar scores for the same individuals, because of the considerable variability implied through the model's foundations and the flexibility of its factorial design.

2.2.13.3   Implications for pedagogy and evidence of pedagogical impact

Vermunt's tool was developed specifically with university students in mind and as a research tool for educational and pedagogical purposes. The model itself is simple and its learning curve is not a hindrance. Furthermore, the vocabulary upon which it is built facilitates use and communication among both educators and practitioners. Vermunt's ambitions span the notoriously ambiguous "matching" of learning styles between students and tutors, and between students and their learning environments, to an interesting prospect in the form of diagnosing maladaptive learning approaches, where students combine factors from different learning styles that do not produce a synergistic means to facilitate learning in given contexts.

2.2.13.4   Applications

Vermunt's model gained considerable robustness in focusing exclusively on higher education, producing a reliable self-assessment methodology to improve pedagogical strategies, tools, and even a simple and effective vocabulary to facilitate communication between researchers and practitioners. Other contexts of use for the ILS are less known, with one study on secondary vocational education by Slaats, Lodewijks, and Van der Sanden (1999) showing limited successes in the use of the ILS' constructs. It has also been shown that the ILS is a rather poor instrument in cross-cultural studies, according to a study by Kolody, Conti, and Lockwood (1997). No references have been found on the topic of business, corporate cultures and the use of the ILS, nor in the areas of e-learning and distance education.

2.2.13.5   Overall assessment

Coffield et al. are favourable to certain aspects of Vermunt's model, such as the customization of a learning style tool specifically for higher education, the robustness and reliability of the inventory, and its flexibility, modest assumptions, and its reasonable set of concepts, which all facilitate communication about learning styles. The main problem is a lack of substantial empirical validation for the ILS, and the absence of clear and practical recommendations for the implementation of educational strategies and pedagogical measures aimed at improving the learning experience. Whilst the ILS was designed with flexibility in mind and acknowledges changes in approaches to learning among students, this very characteristic also substantially reduces the tool's potential to predict performance.

2.3   Summary of Learning Style Models

This section presents a summary of the learning style models based on the review of Coffield et al. The learning style models are presented in Table 1 in the order that they were discussed within the preceding content of the report. That is, according to where they fall on the continuum that was put forth by Coffield et al. At one end of the continuum there are theories that envision learning as derived from fixed factors, which are dependent on cognitive styles more so than learning styles. At the other end of the continuum, there are theories characterized by views of learning styles as flexible preferences, strategies, and approaches. The fixed factor theories are presented first, and the flexible preference theories are presented last in the table.

Table 1. Summary of the review of 13 learning style models

	Strengths	Weaknesses	Applications
Dunn and Dunn	• Simple model, extensively applied in pedagogical contexts.	• Unwarranted connections with neuroscience and physiology. • Lack of independent reviews	• Classroom • E-Learning
Gregorc's GSD	• The GSD taps into the unconscious cognitive processes involved in the assimilation and integration of information: perception and ordering.	• Learning styles are seen as immutable features. • The theory appeals to vague and ambiguous constructs, and the psychometric tool has received considerable negative criticism regarding its reliability and validity. • Little support for the GSD's pedagogical implications.	• Classroom
Riding's CSA	• May have important implications for teaching: it is plausible that teaching which is biased towards any one of the extreme poles of the model would disadvantage some learners. • Shows evidence of links between cognitive styles and instructional preferences in computerized instruction.	• Reliability and validity issues. • Two very specific tasks bear the weight of broad and loosely defined constructs. • Performance is sampled over a very limited range of task difficulty. • The flawed CSA tool does not support Riding's model.	• Classroom • Business
Apter's MSP	• An interesting alternative to fixed-traits constructs.	• A measure of personality, not learning styles specifically. • No research about pedagogical implications.	• Business

Jackson's LSP	• The LSP is a sophisticated instrument in terms of its theory base and computerized format. • Computer provides recommendations for personal development that result from completing the questionnaire • Designed for use in business and education. • The authors claim factorial validity on the basis of a four-factor solution. • Some evidence of concurrent validity is provided by correlations with other measures of personality.	• Learning styles are here understood as one component of a relatively stable personality type, not a cognitive structure. • Each of the LSP scale includes a number of rather loosely associated variables and often the generic label is not the most appropriate one. • The "reasoner" scale has poor test–retest reliability.	• Classroom • Business • E-Learning
Myers-Briggs' 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.	• Classroom • Business • E-Learning
Allinson and Hayes' 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	• 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 (i.e., intuition and analysis are not opposite, mutually exclusive features). • The popularized stereotype of left- and	• Business

	treated as a measure of two factors rather than one. • Matched styles are often effective in mentoring relationships.	right-brained-ness creates an unhelpful image of people going through life with half of their brains inactive.	
Herrmann's HBDI	• Tested exhaustively in business contexts. • Theoretical background is compatible with many CLS models. • Psychometric tool has been assessed to be fairly sound.	• No research on pedagogical applications (but business studies make HBDI appear like a promising venue).	• Classroom • Business
Honey and Mumford's LSQ	• LSQ probes the attitudes and behaviors that constitute the basis for learning preferences. • To be used for personal/organizational development and not for assessment/selection. • Not a psychometric instrument, but a checklist about how people learn. • Suggestions made to help people strengthen an under-utilized style.	• Learning styles are here understood as flexibly stable learning preferences, not a cognitive structure. • Danger of labelling people within one style or another without considering combinations of styles – Potential for stereotypes or mislabelling. • Poor predictor of students' performance relative to preferences.	• Business • E-Learning
Kolb's 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	• Classroom • Business
Entwistle's ASSIST	• Model aims to encompass approaches to learning, study strategies, intellectual development	• Complexity of the model and instruments is not easy for non-specialists	• Classroom

	skills and attitudes in higher education.	to access.	
	• Considerable literature validating the model and theoretical background.	• Danger of categorizing or stereotyping learners' characteristics if theory and model not known in depth.	
	• Teachers and learners can share ideas about effective and ineffective strategies for learning.	• There is a large gap between using the instrument and transforming the pedagogic environment.	
Sternberg's TSI	• Thirteen thinking styles are proposed, based on the functions, forms, levels, scope and leanings of government.	• Need for independent evaluation. • Implications for pedagogy not substantiated by empirical research. • Limited or inexistent support for reliability and validity.	• Classroom
Vermunt's ILS	• It applies to the thinking and learning of university students and instructors. • Includes learning strategies, motivation for learning and preferences for organizing information. • Learning style-worthy components of the model: cognitive processing, and mental model of learning.	• Says little about how other personality traits interacts with learning style. • Not applicable to all types and stages of learning, excludes preferences for representing information. • Not a strong predictor of learning outcomes. • Emphasis not on individual differences, but on the whole teaching–learning environment (not our purpose with learning style models).	• Classroom

2.4 Summary of Implications for Pedagogy and Evidence of Pedagogical Impact

To date, Coffield et al.'s review is the single and most impartial review of the literature on cognition, learning, and pedagogy. However, this review is clearly not definitive, nor is 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. An increase in self-awareness about learning styles, preferences, and strategies should benefit pedagogical approaches, as giving tutors and students some common language by which they can assess their understanding about their own learning styles is intuitively beneficial.

Other opportunities for the implementation of learning style models appear less fruitful: career counselling and personnel selection are not recommended based on the observation that the psychometric tools available remain largely unvalidated. 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.

Coffield et al.'s most vehement criticism 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, 1998) 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 complied 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 Coffield et al. 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). As a result, this review has included updated and detailed support for the use of the ILS within the proposed ITS, and these new findings are the focus of the subsequent section.

3 The Felder-Solomon Index of Learning Styles and its Applications

This section provides an overview of Felder-Solomon Index of Learning Styles. In addition, this section introduces an adaptive learning aid (LOCATE^{TM}), 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 LOCATE^{TM} do appear to be very similar to those assessed by the ILS. As such, LOCATE^{TM} 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.

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 Coffield et al.'s category of learning styles as flexible traits. 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 (Litzinger, Lee, Wise, & Felder, 2007).

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). Each scale consists of 11 items, leading to a total of 44 items in the ILS. 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?

    o Active learners prefer to process information by talking about it and trying it out (e.g., they prefer active student participation in groups).

    o 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?

    o Sensing learners prefer to take in information that is concrete and practical.

    o 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?

    o Visual learners prefer visual presentations of material: diagrams, charts, graphs, pictures.

    o 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?

    o 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.

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 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 minimum standard of .50 that was suggested by Tuckman (1999) for preference and attitude assessments. These coefficients 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 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.

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.

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.

3.5   Application of the ILS at DRDC: LOCATE^{TM}

LOCATE^{TM} (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^{TM} 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^{TM} is an adaptive help system, which plays a key role in DRDC Toronto's ongoing efforts to develop and refine adaptive learning technologies. LOCATE^{TM}'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^{TM} asks users to answer a set of questions, as based on the Cognitive Style Questionnaire that was developed by Edwards (CSQ: 2005). According to the CSQ, learning styles fall along a Verbal, Imagery, and Kinaesthetic tri-mension and a Holistic and Analytic dimension (see *Figure 2*).
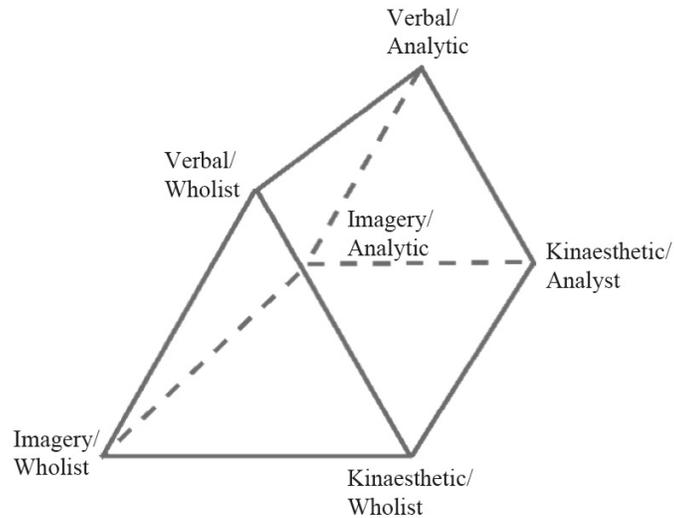
Figure 2. Cognitive style modelled as a triangular solid

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);

- *Imager/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 that 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 and Scott (2005, 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[TM] 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.

3.6   Overall Assessment

A review of 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 the ILS can be applied in business contexts. Finally, as based on favourable outcomes following the DRDC's design of a learning aid called LOCATE[TM], 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   Recommendations

The objective of this study was to identify suitable learning styles for adaptive learning and intelligent tutoring technologies that would improve CF distance learning capabilities. Section **1** of this report introduced the reader to computer-based and distance education, and more specifically, to intelligent tutoring systems. Section **2** featured a comprehensive review of a significant number of learning styles as presented by Coffield et al. Such models have the potential to provide theoretical background for designing educational systems, build their user model and functionality, and guide decisions about what the system should offer to learners, with different styles in the case of adaptive educational systems (Papanikolaou & Grigoriadou, 2004; Karagiannidis & Sampson, 2004). Section **3** provided a detailed review of the Index of Learning Styles (ILS: Felder & Silverman, 1988; Felder & Solomon, 2006), in addition to introducing an adaptive learning aid (LOCATE^{TM}), which is based on the ILS and has been designed within DRDC to aid in the design of workspaces using learning styles. At the end of Section **3**, it was concluded that, as based on supportive research evidence, the ILS should be used within the proposed ITS.

The following are a series of specific recommendations for the use of the ILS within adaptive learning and intelligent tutoring technologies, as based on the preceding three sections of the report.

- 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 Felder – Solomon Index of Learning Styles online questionnaire (Felder & Solomon, 2006) to capture the initial values representing the learner's style.

- Baseline ILS styles should be compared against the style of current ITS course teaching/presentation styles to see if the areas where people are failing are indeed those which show a mismatch between learning and teaching styles, and/or electronic 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 the focus of the design of the ITS's course content should correspond to only three dimensions of the ILS, which will reduce redundancy.

- Although the current work of Edwards and Scott (2005, 2007) involving LOCATE^{TM} 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^{TM} program.

o   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.

o   Furthermore, it should be noted that the learning styles implemented in LOCATE^{TM} 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^{TM}, 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.)

   o   It is recommended that a similar help strategy be adopted for the current ITS. One suggestion is to incorporate an area where operators can practice and "try-things out", or watch demonstrations of interviews done correctly and incorrectly.

   o   Also, learning styles could be incorporated into the hints given by the tutor.

   o   A potential issue to note is the creation of multiple learning style content increases the complexity and work expenditure of the programmers by an immense amount. Therefore, it is advisable to begin by implementing fewer learning styles, and building onwards following a proof of concept.

5   Conclusions

The objective of this study was to review the learning style models in cognitive and educational psychology, and to assess their potential impact on current and prospective e-learning technologies in the context of CF distance learning requirements. In response to the lack of independent support for the reliability, validity, and applications of the models reviewed by Coffield et al., this review was extended to locate new learning styles that had not been reviewed by Coffield et al. The search yielded the Felder - Solomon Index of Learning Styles. As based on strong empirical support for the ILS and the DRDC's development of an ILS-based software called LOCATE^{TM}, it is recommended that the ILS model be used to identify students' learning styles to improve their learning effectiveness.

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List of abbreviations

AC	Abstract Conceptualization
AE	Abstract Experience
ARP	Applied Research Project
ASI	Approaches to Study Inventory
ASSIST	Approaches and Study Skills Inventory for Students
ATCS	Apter Team Contribution System
AWIS	Apter Work Impact System
CE	Concrete Experience
CF	Canadian Forces
CLS	Cognitive Learning Styles
CSA	Cognitive Styles Analysis
CSI	Hayes' Cognitive Styles Index
CSQ	Cognitive Style Questionnaire
DANDIE	Dynamic Asynchronous Networked Delivery of Individualized Education
DRDC	Defence Research and Development Canada
GSD	Gregorc's Style Delineator
HBDI	Hermann's Brain Dominance Instrument
ILS	Index of Learning Styles
ILS	Inventory of Learning Styles
ITS	Intelligent Tutoring System
LSI	Learning Style Inventory
LOCATE^{TM}	A software tool designed at DRDC that aids in the design of workspaces using learning styles

LSP	Learning Styles Profiler
LSQ	Learning Styles Questionnaire
MBTI	Myers-Briggs Type Indicator
MSP	Motivational Style Profile
NATO	North Atlantic Treaty Organization
RASI	Revised Approaches to Studying Inventory
RO	Reflective Observation
TSI	Thinking Styles Inventory
US	United States
UK	United Kingdom
VAKT	Visual, Auditory, Kinesthetic and Tactile learning modalities

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This report summarizes a study examining suitable cognitive and learning styles for intelligent tutoring technologies to improve the Canadian Forces (CF) distance learning capability. The study was motivated by the CF's requirement for computer-based training in a distance educational context to improve learning effectiveness. Through extensive research, Defence and Research Development Canada -Toronto has deemed that advanced e-learning systems are the appropriate tool to address CF learning needs, as e-learning systems:

- Cater to all individuals in the CF regardless of their cognitive or learning style;

- Allow CF personnel to work at their own pace and remotely;

- Cut costs and optimizes learning productivity;

- Equip the CF and DRDC with emerging and cutting edge technologies; and

- Advance the knowledge base of defence science.

The study involved collating applicable academic research literature to gather data. Potential suitable cognitive and learning styles for Intelligent Tutoring Systems (ITSs) were examined and analyzed. Although most cognitive and learning styles were inconclusive and indefinite due to a lack of independent validation data, the Felder Solomon Learning Styles Index has been validated. Thus, it is recommended to be used in an ITS to identify students' learning styles for the customization of their learning experience.

Pendant que les forces canadiennes (FC) démontrent leur promptitude pour la formation à distance, il est impératif de comprendre les défis qui peuvent accompagner la technologie et les approches utilisées. Recherche et développement pour la Défense Canada (RDDC)-Toronto a identifié ces défis et par conséquent, un projet de recherche appliquée (PRA) en 2008 est lancé. L'objectif de l'PRA est de progresser la base de connaissance de la science de la défense, étudier des nouvelles et émergentes technologies de formation à distance et explorer l'application militaire de ces technologies à l'intérieur du FC.

Une des activités les plus provocantes pour un facilitateur de la formation à distance sera de fournir un degré de réponse, le même ou plus élevé qu'un Tutorat au étudiants et customiser l'expérience d'enseignement au style d'apprentissage d'un individu. Un des mécanismes pour faciliter l'expérience d'enseignement est un apprentissage adaptif à travers des technologies des tuteurs intelligents. Pour rendre la technologie efficace dans un environnement de la formation à distance, les styles d'apprentissage d'étudiant doivent être étudiés avant de mettre en application n'importe quelle technologie, afin de faciliter la customisation d'une expérience d'apprentissage d'étudiant.

L'objectif de cette recherche était d'identifier des styles d'apprentissage appropriés pour les systèmes Tuteurs intelligents (STI) qui amélioreraient le potentiel de la formation à distance de CF. Dans cette recherche, 13 styles cognitifs et apprenants, les plus influents ont été examinés comme ils sont basé sur la littérature précédente. La révision n'a trouvé aucune évidence empirique pour la fiabilité, la validité, et les applications des 13 styles. Apres, la recherche a été prolongée pour rechercher la littérature concernant des styles cognitifs et apprenants d'après le

scientifique, la défense (par exemple, la défense des USA et des rapports de l'OTAN), la gouvernement (par exemple, archives de RDDC) et les sources basées sur Internet. La recherche a mené à l'Index d'Apprentissage de Felder-Solomon (ISA) qui a un appui empirique fort. En plus, RDDC a développé une aide d'apprentissage basée sur ISA pour le logiciel de conception des lieux de travail appelé LOCATE^{TM}. Ainsi, il est recommandé qu'ISA devraient être employé comme modèle dans un STI pour identifier les styles d'apprentissage des apprentis de CF, subissant la formation assistée par ordinateur pour améliorer leur efficacité d'apprentissage.

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learning style, cognitive style, adaptive learning, intelligent tutoring, computer-based training, e-learning, distance learning, learning customization

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