Universal Design for Learning in the Framework of Neuroscience-based Education and Neuroimaging-based Assessment

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***Abstract*— Universal Design for Learning (UDL) has been proposed to facilitate the training processes and improve the learning outcome. The article reviews the theories in neuroscience-based learning and evidences of brain imaging studies that relates to the principles and design of UDL. Neuroimaging based assessment strategy is also reviewed as it may provide an objective means of evaluating learning outcomes in the application of UDL. Then, the challenges and opportunities in using brain imaging in UDL are identified and discussed. Finally, we discussed the need of UDL principles, its implementation, and evaluation via neuroimaging technologies in the framework of neuroscience-based education for professional training in air traffic controllers at the Federal Aviation Administration (FAA) Academy.**

Keywords—universal design for learning, air traffic controllers, neuroimaging, wearable technology

I. INTRODUCTION

The article review the challenges at the intersection of universal design for learning (UDL) [1] and neuroimaging-based assessment, and the opportunities to improve the professional training in air traffic controllers by combining UDL and neuroimaging. The challenges include: 1) building the linkage between UDL and neuroscience based learning; 2) reasoning the value of brain activity monitoring technologies in evaluating UDL and discussing their current advancements and challenges; 3) extending UDL to professional education, i.e. air traffic controllers. The objectives of the review are to present the needs of UDL in the domain of professional education beyond conventional school and college education systems, and to justify the values of wearable technologies in evaluating UDL in the context of professional education for air traffic controllers.

II. NEUROSCIENCE BASED LEARNING

Neuroscience based learning has been debated for decades. While much of our understanding about the human brain has been transformed into strategies on learning [2-5], many researchers have argued the distance from neuroscience to education and potential pitfalls due to the incomplete links between two [6-7]. Towards addressing the gap in the understanding of neuroscience and education, an emerging perspective by Colvin in 2016 [8] proposes a three-stage cascading link. As illustrated in Fig. 1, the "neural processes", which is a well-studied mainstream subject in neuroscience, was linked to the user-end "academic tasks", which lie in the education domain, through an instrumental middle layer of "cognitive processes", which falls in the research domain of psychology. Examples of processes at each level that can be researched by scientific methods in each category have been given in Fig. 1.

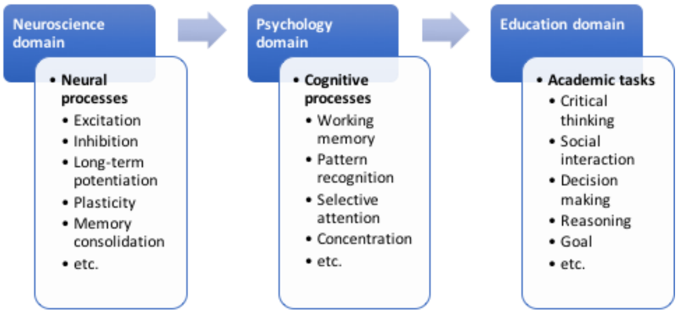

Fig. 1. Schematic link between understanding of neuroscience, psychology and education.

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Based on such a concept, authors of the paper argue that understanding of neural processes can be transformed to improve academic performance through optimizing, generalizing, and integrating current and/or new instructional techniques.

The value and effectiveness of linking neuroscience to education need to be evaluated and validated, which is traditionally conducted using conventional behavioral measures, including accuracy and reaction time [9]. During the learning process, especially for professionals, the progression from a novice to an expert is suggested by the improvement in the relevant behavior measures. However, behavioral measures are limited as single static aggregated metrics for outcomes from underlying interactive multi-dimensional neuronal/cognitive processes, which ranges from sensory to cognitive to motor functions. It has been further suggested that "the focus of the neuroscientific aspect of collaborative research should be on the activity of the brain before, during, and after learning a task, as opposed to using simplified performance evaluation measures only after performing a task" [8]. The reasons are: 1) a novice and an expert might have same accuracy data for a task but time and effort taken to finish the task can be significantly different; 2) learners at different stages might have same total time spent on a task, but the time spent at individual functional brain areas can be significantly different, which indicate different learning effectiveness on different aspects of the task.

Therefore, in order to overcome the limitations of behavior measures discussed above, physiological measures have been suggested as complementary means [10-12], including the physiological measures acquired by neuroimaging. It is suggested that physiological measures, combined with behavioral measures, can be dynamic, multi-facet, detailed metrics for evaluating learning and delineating potential problems in multi-stage of learning.

III. UNIVERSAL DESIGN FOR LEARNING

Universal Design for Learning (UDL) is a set of principles that have and are being developed and advocated for curriculum development that give all individuals equal opportunities to learn as defined by the National Center on Universal Design for Learning [1]. Several aspects of UDL have been proposed for special education [13], while most aspects have been generalized to address individual variations on learning [14-15], an important aspect for professional training.

The formulation of UDL principles has been closely tied to neuroscience-based education [16]. *Recognition Network* (mainly occipital, temporal, and parietal lobes) is the neuronal basis for how learners gather information and categorize information from seeing, hearing, and reading. *Strategic Network* (mainly frontal lobes) is the neuronal basis for how learners organize and express idea. *Affective Network* (mainly cingulate cortices) is the neuronal basis for how learners get engaged (See details at http://www.udlcenter.org/). Despite the links between neuroscience and learning in general, there has been no systematic analysis on how UDL principles can be mapped into learning processes constructed from neuroscience principles and how exactly these principles promote learning based on the working mechanism of the human brain. The delay of research in this aspect might be due to the fact that UDL has been focusing on providing materials that work for everyone and the fact that mechanism pathways themselves for neuroscience-based learning are still under debates and being constructed [8].

Nonetheless, there is opportunity to connect the UDL Guidelines Version 2.0 (http://www.udlcenter.org/) and the structure of correlations between neuronal process, cognitive processes, and academic tasks in [8]. It is worthwhile to note the potentials to construct concrete UDL practices based on specific neuroscience principles. Basically, UDL is proposed more from the perspective of education: 1) how to present materials to learners (Principle I: Provide Multiple Means of Representation); 2) how to assess the learning (Principle II: Provide Multiple Means of Action and Expression); 3) how to motivate the learning (Principle III: Provide Multiple Means of Engagement). However, if we consider the details of guidelines and checkpoints under each principle, academic performances that are aimed to improve in these principles are through cognitive processes (the second level in the Colvin's map). Here are several examples.

Under UDL Principle 1 Guideline 1: Provide options for perception, information need to be provided through different modalities and in a format that allow for adjustability by the users, which is related to the "Pattern recognition" in the cognitive process. The Guideline 2: Provide options for language, mathematical expressions, and symbols under the UDL Principle 1 addresses the "Symbol recognition" in the cognitive process. Names of some guidelines even directly indicate such natural relationships (e.g., Principle 2 Guideline 6: Provide options for executive functions). Under Principle 3, Guideline 8 provides options for sustaining effort and persistence, thereby addressing the "attention" in the cognitive processes. The relationship between UDL principles and guidelines and cognitive processes are not limited to these examples, and appear across all UDL principles and guidelines. Therefore, the integration of UDL principles and the neuroscience-based education can be achieved at the level of cognitive processes, while practically each implementation of UDL principles may be mapped to specific cognitive processes. Such a mapping relationship can further help developing protocols to evaluate and validate these practices and implementations.

IV. BRAIN IMAGING AND WEARABLE TECHNOLOGIES

Physiological measurements used for evaluating learning are brain signals including bio-signals measured by electro-encephalograph (EEG) and hemodynamic responses measured by functional magnetic resonance imaging (fMRI). These brain imaging technologies have been widely used in understanding learning and processes of learning [5], which also provide neuroscience evidence on optimizing, generalizing, and integrating current/new instructional materials and techniques. For example, fMRI and positron emission tomography (PET) have been used to show how the medial prefrontal cortex, right premotor, left anterior intraparietal sulcus (IPS), right anterior IPS, left posterior IPS, right posterior IPS, and the left inferior temporal cortex are activated while attention is shifting [17]. Another example is that fMRI can show how a person's neural activity increases as they learn new things, but as the new things become recognizable, neural activity decreases with time [18].

fMRI also has been used to show how neuronal activities in the hippocampal region decrease while the activities in the medial prefrontal cortex increase as they are learning for a long period of time [19].

These technologies have been used to investigate UDL principles and practices as well. For example, fMRI was utilized to understand the barriers caused by syntactic and structural relationships in information provided for learning [20]. EEG signals were used to understand different cognitive processes observed [21] and fMRI was used to investigate different cortical activations [22] both with the use of multimedia for learning materials. All these studies are more related to the UDL Principle I and few brain imaging studies have been conducted related to the UDL Principles II and III (UDL principles were elaborated in the above Section III). The fact does not mean that brain imaging technologies cannot be used for studying these UDL principles. Many cognitive processes in [8] have been investigated in the literature of brain imaging [5-6]. If the mapping relationship between UDL and neuroscience based education can be established as discussed in Section III, protocols can be developed to study them as well. However, in summary, UDL principles and guidelines have not been systematically investigated using neuroimaging tools, which present both the limitation and opportunity at the same time.

One of the main challenges using brain imaging technologies in learning is how to use these sophisticated instruments in the natural environment at where the learning occurs. Many noninvasive brain imaging technologies, such as fMRI and magnetoencephalography (MEG), have been utilized in studying neuroscience about learning. However, such imaging facilities are constrained by costly, bulky, fixed hardware that preclude imaging of the functioning brain in a wide range of temporal and naturalistic environments in which humans interacts and learns. Another critical limitation of fMRI is its low temporal resolution which is not sufficient to capture the dynamics of neural activities associated with learning processes. Recent advancements in wearable sensing technologies, however, can make significant contributions. A portable EEG system based on dry electrodes, wireless data transmission and customized ergonomics, as shown in Fig. 2, has been established Ding, Yuan, et al. EEG has superior sampling resolution of larger than 100 Hz. Dry electrodes can shorten the preparation and make the system ready to use in a few minutes. Battery-based power and wireless-based transmission of data allows for subjects performing a learning task in a natural environment. Additionally, data processing pipelines [23] have been developed to automatically remove the muscle-related artifacts and extract neural networks that are closely related to the attention, memory and learning processes. With the existence of these technologies and the link between neuroscience-based education and UDL, it is possible to develop protocols to evaluate the effectiveness of UDL principles and guidelines, as well as to help design effective UDL implementations for specific purposes that will be discussed in the next section.

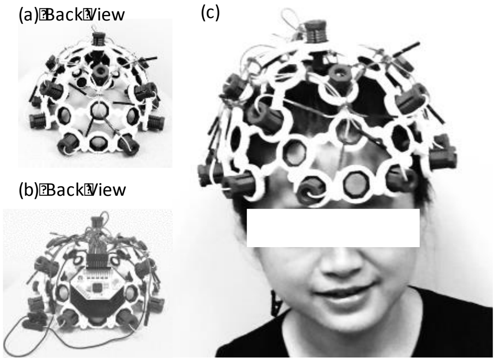

Fig. 2 3D printing of wearable sensing device for EEG. (a) and (b) are frontal and back view of the cap. (c) illustrates the customized cap on a subject. Note that no data cables or gel prepration is needed for brain imaging.

V. PROFESSIONAL TRAINING FOR AIR TRAFFIC CONTROLLERS

One important future application of UDL is to potentially apply the UDL principles to the domain of professional training for air traffic controllers, beyond sharing with the community about the linkage between UDL and neuroscience based education and means to evaluate the effectiveness of UDL practices based on such a linkage. In this regard, several EEG studies have been conducted to identify brain imaging biomarkers in learning and in distinguishing novice and experts in the context of air traffic controllers.

Key training aspects for air traffic controllers are to build certain cognitive capacity. In the meantime, many of the existing challenges in Federal Aviation Administration (FAA) academy training can be represented in the three key domains of UDL [1]. An example in the representation domain is that the learning materials available to students are desired to be in a multi-media format, in multi-dimensional scenarios that allow audio respond and text captioning. Another example in the domain of action and expression is new tools of online communications, or virtual reality (VR) applications that allow more time to practice, whereas conventional lab time has been very limited for students to practice. In the domain of engagement, the challenge persists about how to engage students and current air traffic controllers to form a large community of collaboration and integration. A great number of courses in their training are hand-on training with various complex systems. The interaction and adaptation at the interface between learners and these systems are critical for the training of novices. The UDL in the curriculum design is therefore much needed.

To implement UDL principles in the training of air traffic controllers and evaluate its effectiveness, several steps might need to follow: 1) perform content analysis of the current education materials at the FAA Academy; 2) identify key skills that air traffic controllers are being trained; 3) develop appropriate UDL practices for better training; 4) map them to specific cognitive processes being targeted; and 5) utilize brain imaging technologies to evaluate its effectiveness. It is our analysis, from section II to IV, that the procedures and links among these individual steps have been existing. It will be our future efforts in practicing UDL principles in the framework of neuroscience-based education for professional training to air traffic controllers.

VI. CONCLUSIONS

The link between UDL and neuroscience based education has been reviewed. The training needs for air traffic controllers seem aligned with those being promoted by the UDL principles. Brain imaging technologies have been used for evaluating learning in general, UDL, as well as learning in air traffic controllers. At the same time, the evaluation of UDL principles has not been systematically performed and tools that could be used to evaluate UDL implementations are not available as well. Therefore, brain imaging technologies, together with performance measures, can be used to evaluate the practice of UDL principles in the framework of neuroscience-based education for professional training. Particularly, recent development in broadly accessible brain imaging technology, such as wearable devices and high-performance computations, are expected to accelerate the study of UDL in professional training.

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