UNIVERSAL DESIGN FOR LEARNING (UDL) FOR STEM AND HIGHER EDUCATION: CHARACTERIZATIONS AND APPLICABILITY

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Abstract: Universal Design for Learning (UDL) seeks to reach all students through accessible and flexible curriculum that matches their learning pathways and increases their ability to perceive, understand, and actively apply new skills to various applications. A cohesive review of the pivotal UDL approaches is provided along with how those pivotal approaches can be further implemented into not only K-12 STEM education but also higher education. UDL applications in the general curriculum will be expounded upon and illustrated with practical approaches instructors can take to achieve UDL in their classrooms. Strategies for effective implementation and recommendations for the future of UDL will be discussed, specifically in the context of FAA operational training.

Keywords: Universal Design for Learning, Air Traffic Control

1. INTRODUCTION

The scope and application for this research stems from the FAA's need for more air traffic control specialists (ATCSs) with the recent retirement of many specialists. To better and more effectively train the new controllers, the FAA is considering implementing Universal Design for Learning (UDL) principles into their training curriculum. This research will consider the characteristics of UDL to determine if it is possible to apply these principles to the FAA training programs. If so, the examples provided of UDL will be mapped to situations encountered in air traffic controller training.

The path to implementation of more flexible and universal education came through years of legislation, beginning in the late 1970s. In the 1990s, the No Child Left Behind Act was pursued by Congress to standardize assessment and learning criteria across the country [1]. The primary focus was to provide students with learning materials under the same standards. Now, curriculum needs to be flexible to fit students of varied learning and linguistic skills to meet the standards in high stakes testing with these regulated measures. Universal Design for Learning (UDL) seeks to meet all students and apply methods of teaching that fit students' needs and ability while appropriately challenging their skills through providing multiple means of representation, action and expression, and engagement [2-3].

There are three brain networks that play an integral role in the learning process. First, recognition networks are responsible for the "what" of learning, specifically, the content and facts of the lesson. They detect patterns and allow people to understand information they perceive. Second, strategic networks dictate "how" a student learns and demonstrates what they have learned. This part of the brain applies strategy and develops the problem-solving process of planning, executing, and monitoring the response of thinking and performing actions. Last, affective networks provide the "why" of learning—the motivation that allows a student to focus and pursue learning the material. They apply the patterns people perceive and give them meaning, allowing engagement and focus on the task at hand [4]. The classification of these brain networks map to the UDL guidelines of representation, action and expression, and engagement. Each of these networks work laterally across the areas of the brain and function in parallel, such as simultaneously analyzing shape and color. Also, they work in hierarchical processes—either bottom-up, perceiving and applying information from the environment, or top-bottom, applying previously known context to the environment [3].

Traditional methods of teaching typically feature one pathway of recognition, rather than recognizing the distributed and hierarchical nature of perceiving and understanding patterns that can be different among the students. UDL expands upon its original purpose of reaching children with disabilities to also include those who struggle academically, those who speak English as a second language, and those from different cultural and socioeconomic backgrounds. UDL adapts the curriculum to meet diverse students rather than trying to fit students into the curriculum. To achieve learning that effectively reaches all students, curriculum must be flexible and provide a balance of supports and challenges to students. Furthermore, technology allows for "differentiated instruction," giving teachers the ability to better create criteria to measure an individual's success, provide teaching methods that fit a student's learning networks, and develop assessment strategies to supervise a student's progress [5].

2. SETTING GOALS THROUGH UDL

Access to the curriculum needs to be designed to not undermine the learning objectives. Setting clear goals and determining the intention of the lesson will help distinguish UDL tools that can increase the accessibility of the curriculum but will remain challenging to meet objectives for students. Setting clear and appropriately focused goals is a critical first step in the implementation of UDL in classrooms, and goals should be oriented to challenge but not to overwhelm the student [4,6]. When expressing goals clearly, teachers should ensure that one specific path is not stated in an absolute manner, allowing for a more flexible approach for students. Then, support and other structures can be designed to assist students.

3. METHODS FOR UDL

Material should be varied and applied to multiple types of media to support students [6]. Especially, digital options to display text in different colors and sizes along with auditory options may be better than the traditional printed text. Additionally, digital media can support links to references, dictionaries, background information, and other helpful resources for students. Questions of understanding, chronological steps, and content organizational functions may also be beneficial for learning comprehension.

When digital methods of teaching are used in the classroom, they provide flexibility to learning that traditional methods cannot offer [3]. In detail, they should be "versatile, transformable, annotatable, and networked." Versatile methods include multiple ways of viewing the content (e.g. combinations of text, images, and videos). Transformable methods allow changes within the medium; for example, changing color and text size of a digital book. Additionally, students should be able to write on and highlight the medium (i.e. annotatable methods) while being able to connect to dictionaries and web links with additional background context (i.e. networked methods).

The UDL guidelines for representation, action and expression, and engagement can be applied to create flexible materials and methods for students [4]; however, teaching should balance challenge and support to students within the "zone of proximal development" that creates challenges but does not frustrate students [6-7]. Curriculum guidelines, along with easy examples that can be applied to STEM education, are cohesively structured to show ways to provide scaffolds for increased comprehension and memory.

3.1. Representation

Information should be provided through varied means, especially through many examples and counter-examples [3]. For example, highlighting critical features by supporting bottom-up processes or by offering multiple forms of media allow students to learn the material by supporting their learning style and by adding redundancy. Providing background information is also important to help scaffold top-bottom processing and to provide context for students [4].

The highest priority in providing scaffolds for increasing comprehension and memory is to provide interlinked contextual or diversified background information of unfamiliar terminologies. Examples of how these concepts are used in STEM education can be further implemented into higher education are shown in **Fig. 1** and **Fig. 2.** As students move on to receive higher education, concepts are less visualized and explanations of difficult terminologies are not interlinked nor decomposed into easier vocabulary. As shown in **Fig. 2,** diverse options can be provided to help students better learn a difficult concept or vocabulary (i.e. "induced roll") rather than providing a series of other difficult vocabularies to define it. The important underlying idea is to help students create a cognitive network (or hierarchical) model of their semantic and episodic memories for easier and faster retrieval of newly learned concepts or vocabularies.

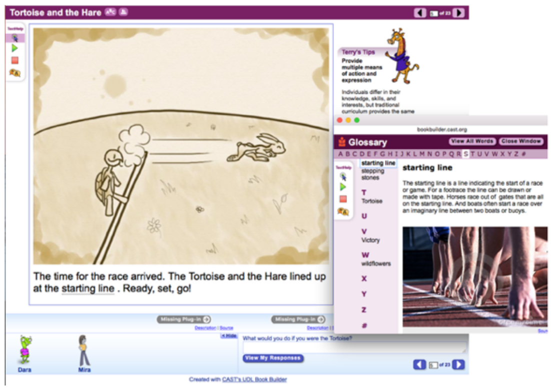

Fig. 1: Representation example - Tortoise and Hare story from the UDL Book Builder shows how an unknown terminology ("starting line") can be interlinked with definitions [8]. The definitions can promote higher level concepts such as the equal and fair opportunities even if individual traits are different. This UDL design can increase students' retention of semantic and episodic memories based on the network memory store model of human brains.

In addition, students can keep checklists, divide long instructions into attainable tasks, make estimations, detect patterns, and highlight key concepts to enhance learning effectiveness. Instructors can also actively assist students by recalling prior knowledge and connecting new skills to an application. Implementation of UDL in higher education has proven to be effective [9-11] even in applications of graduate nursing programs [12] and educational gaming web applications [13].

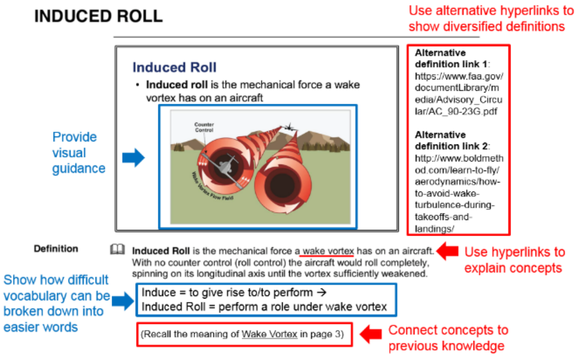

Fig. 2: Representation example - Explaining a complex concept in higher education (e.g. FAA operational training) using the UDL principles. In addition to providing interlinks of diverse definitions, learning can be supported through visual guidance, decomposing vocabulary into easier words, and connecting concepts with previous knowledge.

3.2. Action and Expression

Flexible methods for action and expression assist students in developing a problem-solving approach and guiding their efforts to accomplish a certain goal [3]. In detail, support of strategic learning networks includes demonstrating flexible examples of expert performances to develop patterns for how to accomplish a task. For a student to develop strategies internally, they need to be exposed to correct and incorrect examples to learn the models for themselves. Students need to have multiple opportunities to practice their skills with supports to begin to automatize the procedure and eventually, perform it without supports. Feedback that is continual and applicable is critical to develop strategic networks [4].

Some pertinent methods include helping students with organizing their writing into steps and showing examples at each step. Not only instructor feedback but also peer feedback might play a critical role for the students to effectively learn. In addition, instructors can provide demonstrations and share different techniques to connect previous knowledge and experiences. An example from CAST Science Writer software [14] is shown in **Fig. 3.**

In addition, STEM education can be promoted through collaboration tools to collect data during experiments, share tasks, and discuss results among peers. Furthermore, instructors should encourage students to take self-organized notes and should provide timely feedback so that students can sustain their semantic and episodic memories.

The framework of feedback and collaboration software can be applied not only to K-12 STEM education but to higher education in science, technology, and engineering. An example is shown in **Fig.4**. The state-of-the-art technologies available today can enable students to engage in actions and expressions among instructors and peers in real time to provide or receive feedback.

Fig. 3: Action and expression example - CAST Science Writer illustrates how it guides students in writing technical papers by providing the outline of the report, directions for support, a checklist, and examples for reference.

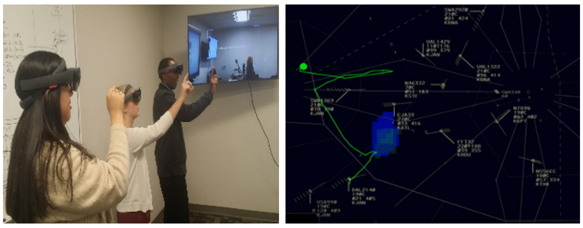

Fig. 4: Students sharing the same visual field of view using HoloLens (left side figure) at the Federal Aviation Administration that can enable them to observe and discuss about the instructor's (or peer's) eye movements overlaid onto an air traffic control radar display for an aircraft conflict detection task (right side figure) in real time. Technologies enable real time collaboration, discussion, and feedback.

In FAA operational training, concepts can be mapped to air traffic control tasks such as mitigating possible aircraft conflicts (i.e. collisions or loss of separations). Conflicts can be averted by different means, such as altering the altitude, direction, speed, or a combination of any of these. Some methods might mitigate the conflict more quickly, but those methods may not necessarily be the most efficient (regarding fuel consumption, for example). Tradeoffs between efficiency and safety can be viewed differently by each individual student, and therefore, the scaffolding technologies can allow the students to freely discuss and apply different types of strategies under various mitigation situations.

3.3. Engagement

Flexible means of engagement serve to motivate and challenge students [3]. Rose and Meyer [3] assert that learning should give options of subject context and tools to the students to increase interest and engagement, and ultimately enhance affective networks. Creating the appropriate and adaptable level of challenge is important to motivate affective networks. If the task is too difficult, students are likely to become frustrated; but if it is too easy, students will disengage from the material from boredom. Giving options of rewards and of the learning environment will help motivate and involve students in the curriculum [4].

Relevant methods include providing students with an option to add or remove supporting materials based on their need to either prevent frustration or boredom. This teaches students to self-regulate their own progress to accomplish goals, connect concepts to their everyday life observations, and offer various challenges and supports by student need. These methods can be applied universally in both K-12 STEM and higher education.

4. UDL ASSESSMENT

Applications for student assessment should also be designed through UDL standards. The means in which an assessment is delivered affects the performance of the student. This effect may not be significant for every student, but it certainly can be deleterious on a few. For assessment of students to be effective, it must apply the flexibility and adaptability inherent to UDL. This allows students to be tested over the material and content they are learning without providing unnecessary difficulties of the assessment format [15].

Modes of assessment can also be better adapted with digital media to provide a more flexible, relevant, and current status of student progress. When individual learning differences, medium preferences, lack of support, and poor integration influence assessment, a student's ability cannot be accurately understood and advanced appropriately. Models of dynamic assessment allow the teacher to understand the learning process of the student better than a grade assigned at the end of the class [3]. More interactive and dynamic evaluations better indicate the level of support, problem-solving approaches, actions, and bias that are influencing the student and contributing to their success or failure. It is easier to adapt the curriculum throughout the class instead of waiting for an assessment period at a time when the material must already be learned. Assessment strategies that incorporate UDL can better adapt curriculum and teaching strategies to the student's needs [15].

It is also important that students are aware of their own progress through assessment methods [6]. It is best to incorporate assessment into the teaching curriculum to give students better feedback on their performance. As students are proceeding through the curriculum, they should be able to learn and assess their own progress in active feedback. Additionally, continual assessment can reduce some of the stress incorporated with testing as the test is not an additional obstacle and perceived indicator of failure—which lessens engagement [15].

In addition, culture influences the values and beliefs that shape the worldview of the student. Therefore, it is important that curriculum validates and supplies illustrations that are familiar to the student's culture. If a student is placed too far out of their comfortable sphere for learning, it can cause a cognitive strain on the student and can lead to behavioral problems or fatigue. It is, therefore, critical to understand the cultural influence on the student to allow for optimal learning [16].

5. IMPLEMENTAION AND SUSTAINABILITY

As UDL reaches its next stage of implementation, it becomes critical to transform theory into application by establishing clear and defined objectives to ensure its durability for the next decade. For UDL to be effective in the future, it should be thought of in the context of instructional design rather than architecture (UD) because the social, cognitive, and physical relationships between the student and the curriculum are much more intense and fluid. Diversity, rather than the advantages of technology, should be the focus to ensure that individual students can reach the curriculum with the necessary supports. Design and intentionality of that design should be precise and well-considered for all students. Also, it must be understood that UDL is not simply "good teaching," and that it does not happen inherently without intentionality. UDL is a skill that must deliberately be learned, defined, and applied for it to occur in classrooms. While it is possible to implement UDL without technology, it is a key element for ensuring the success of UDL. The flexibility of digital media allows material to become more accessible and easily adaptable to students. Likewise, UDL goes beyond assistive technology by being available to all students and allowing them to take advantage of the customizable degree of supports and aids needed for their success.

To better support UDL, research needs to include the impact of UDL methods in the classroom to determine if it meets the intended goals and if it contributes to and elevates student success. And lastly, key stakeholders must understand that UDL is more complicated than originally believed and will require new ways of thinking. Techniques and supports need to be modularized for easy implementation and teachers and developers need to understand their responsibilities to make this possible. Considering UDL as part of instructional design can provide the foundational way of thinking to make UDL implementation successful [17].

CONCLUSIONS

In summary, each of the three areas of UDL concepts have an overview of options to create accessibility to all students. For the "representation" phase, different options for perception, linguistics, and cognitive functions should be applied. For "action and expression," instructors should work to increase opportunities for physical activities, communication, and organizational requirements. For "engagement," the material should reflect the student's interests and provide a reason or a motivation for learning the material to add purpose and meaning to the student's learning experience. In other words, the path of learning may be different for each student to suit individual abilities and thinking networks.

In this article, we have cohesively provided the characteristics and applicability of the UDL concepts that have been successfully implemented in K-12 STEM education along with possibilities for implementation in higher education. The investigation for implementations were concentrated on immediate operational training needs of the FAA.

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