From Singular Design to Differentiation: A History of Adaptive Systems

Constructivism is a philosophical paradigm that proposes knowledge construction is based on one's "prior experiences, mental structures, and beliefs" (Jonassen, 1991, p. 10). Because individuals approach learning from different experiences and perspectives, it follows that instructors should attempt to teach in a way that addresses these differences. History suggests scholars have been trying to address the problem of individual differences in educational instruction since the early 20th century (Park & Lee, 2004). Differentiated instruction offers one possible solution to this problem because it supports instructors as they "focus on processes and procedures that ensure effective learning for varied individuals" (Tomlinson & McTighe, 2006, p.3). However, this is challenging in many classroom contexts due to limited time and resources. To move away from a homogenous approach to instruction, adaptive learning systems employ artificial intelligence systems to modify instruction based on the needs of the individual learner. "Whereas early instructional systems considered only one or two variables, newer adaptive systems using computer technology implement models that have multiple layers, each with many variables" (Park & Lee, 2004, p. 471). While different approaches have emerged over time, Graf and Kinshuck (2014) argue that systems have been adapted based on the following learner constructs: cognitive abilities, learning styles, affective states, and the external learning environment. A more recent review of the literature suggests these constructs are still prominent in the learner model (Martin et al., 2020). Moreover, recent historical trends indicate the majority of implementations occurring in higher education(Martin et al., 2020). In the section that follows, we will explore the history of adaptive technologies within these different constructs.

Adapting to the Individual Needs of the Learners

Cognitive Abilities

One of the initial approaches that guided the design of adaptive learning systems includes the cognitive trait model (CTM). Specifically, CTM gathers information from the learning on the following cognitive traits: "working memory capacity, inductive reasoning ability, information processing speed, and associative learning skills" (Graf et al., 2009, p 1282).To further define these terms, working memory capacity refers to the amount of information that can be mentally processed at one time. Inductive reasoning refers to the ability to make generalizations from observations and information processing speed refers to the time it takes to complete a task. Lastly, associative learning skills pertain to the ability of one to make connections between events (Graf et al., 2009). The adaptive system then uses the information from these cognitive traits to adapt accordingly to the learner. Based on these traits, early adaptive versions would develop a learner's cognitive profile and adapt based on their interaction with a learning system. Using these profiles, history indicates the systems would then suggest learning pathways and content best suited for the learner's individual cognitive abilities and prior knowledge (Graf & Kinshuk, 2014).

Learning Styles

In many cases, learning styles typically refer to the visual, auditory, and kinesthetic learning style model that became popular in the early 2000s (Miller, 2001). However as time went on and further studies were completed investigating the visual, auditory, and kinesthetic learning styles model, research suggested that there is no empirical support for that model. (Kirschner, 2017). Whereas prior learning style approaches were defined using the visual, auditory, and kinesthetic model, history suggests that early versions of adaptive systems

employed learning styles in terms of the Felder-Silverman Learning Styles Model (Joseph & Abraham, 2019). Learning styles refer to the idea that students differ regarding the methods of instruction and studying that work best for them (Pashler et al., 2009). In the early 2000s, examples of these types of adaptive systems were designed to adapt to categories outlined in the Felder-Silverman learning styles model (FSLSM) (Felder & Silverman, 1988): sensing/intuitive (perception), active/reflective (processing), visual/verbal (input), and sequential/global (understanding). Joseph and Abraham (2019) define these categories as perception being the information the student typically identifies; processing refers to how the incoming information is transformed into knowledge; understanding pertains to the process the student undergoes to understand said information; finally, input takes into account the methods students prefer to receive information. The systems used the FSLSM model to adapt multiple components to each learner, including examples, self-assessments, exercises, outline, content, conclusion, self-assessments, and conclusion) (Graf et al., 2004). For example, FSLSM would adapt such *active/reflective learners* could learn through multiple rounds of trial and error (Felder & Silverman, 1988). Considering these learning preferences, the system would present a higher number of exercises and self-assessment activities to active/reflective learners at the beginning and end of course content. Furthermore, fewer examples would be presented to the *active learner*, and course outlines would only appear once. In contrast, for *reflective learners*, the system would present the inverse: fewer exercises and self-assessments, more examples, and multiple outline presentations. As time went on, history suggests that combining FSLSM with online adaptive education improves learning (El-Bishouty et al., 2018).

Affective States

As education expanded beyond supporting cognitive abilities, the history of AISs suggests that learning systems were also designed for affective states and motivation (Yadegaridehkordi et al., 2019; Park & Lee, 2004). Examples include systems such as those that are designed to provide "(a) feedback for the current answer with an affective facial expression, (b) an affective statement accompanied by a matching emotional facial and vocal expression by the tutor, and (c) the next dialogue move" (D'Mello, Lehman, & Graesser, 2011, p 7). Over time, the design evolved to design for disengagement and uncertainty (Litman & Forbes-Riley, 2014). Later in history, the AISs designed for affective states were used to address gender disparities in learning and avoid prolonged states of confusion or frustration which can hinder learner motivation (D'Mello, Lehman, & Graesser, 2011; Litman & Forbes-Riley, 2014; Sabourin & Lester, 2013).

Adapting to External Environment

While history suggests that early systems adapted the interface based on learner characteristics (affective, cognitive, learning styles), more recent systems adapt based on the broader external environment (Martin et al., 2020; Graf & Kinshuk, 2014). These systems have especially emerged in informal learning contexts that employ mobile technology (Kinshuk et al., 2010). For example, the French Kitchen program monitors English speakers as they progress through recipes and provides instructions in French to learners (Hooper et al., 2012). Not only are the users learning the language through the act of cooking, but the system is designed to educate on the language's culture. Additionally, adaptive systems have been developed that consider the location of the learner through the use of GPS and the location of peers and experts nearby that could aid in learning (Graf & Kinshuk, 2014).

Recently, the literature shows systems have expanded to include learning activities for the user to complete pertaining to their current external environment. For example, Kinshuk et al. (2010) developed the National Palace Museum Adventure adaptive system using the environmental context, including the artifacts located in the museum and learner preferences. The system then assigns the learner missions to complete within the museum to learn about different knowledge domains. During these missions, learners used the device's interface to gather knowledge about the artifacts in the museum by tapping on the item on the interface once they located it in the museum. The interface provided information regarding the item which was needed to complete the mission (Kinshuk et al. 2010). This type of adaptive learning opens doors for future research for mobile adaptive learning that could offer learners learning experiences in diverse learning contexts.

Future Considerations

The aforementioned history suggests that designers use various ways to adapt instruction. This includes the content and systems that were adapted based on a variety of variables, including cognitive states, learning styles, affective states, and the external environment. As advances in artificial intelligence and mobile technology continue to improve, the literature indicates that adaptive learning systems will continue to be an integral part of supporting instruction to better differentiate and support learning. As AISs continue to evolve, history suggests that successful adaptive systems should consider that knowledge development occurs in numerous ways (e.g - cognitive, affective, content) rather than one singular condition (Spector, 2014).

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