DESIGN, IMPLEMENTATION, AND MEASUREMENT OF PERSONALIZED LEARNING THROUGH THE LENS OF UNIVERSAL DESIGN FOR LEARNING

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Abstract

This dissertation project aims to explore the design, implementation, and measurement of personalized learning (PL) environments through the lens of Universal Design of Learning (UDL). The dissertation consists of five chapters. Chapter One introduces the project and key concepts associated with the topic. Chapter Two provides an analysis of historical and contemporary issues associated with educating diverse learners in standardized learning environments. The analysis sets the stage for the argument that there is a need for applying the framework of UDL to designing PL environments wherein learners can be empowered to become more self-determined. Chapter Three reports on a synthesis of PL research conducted from 2006 to 2019. In order to provide considerations for PL design that supports dynamic development of individual learners, this synthesis integrates the current empirical PL practices into the UDL framework. Chapter Four describes the development of a learner self-report instrument—the Learner-Centered Sensor, which can be used to measure students' learning experiences in UDL-based environments. This chapter also reports on a pilot study designed to conceptually evaluate the tool by generating validity evidence based on its content structure. Chapter Five concludes the dissertation project by providing implications for future research on the design, implementation, and measurement of PL through the lens of UDL.

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Dedication

This dissertation is dedicated to my cousins who deserved a better education opportunity.

Table of Contents

List of Figures

List of Tables

Chapter One: Introduction

Historically, when student performance deviated from the "norm" they were labeled as differing from average students; thus, variations in student learning and performance were often regarded as needing to be "fixed" when standardized instructional designs and approaches failed to address students' diverse needs (Davis, 1995; Lipsky & Gartner, 1997; Skrtic, 1995). Many contemporary education systems still operate under the "one-size-fits-all" and deficit-driven paradigm that perpetuates the existing educational inequalities (Zhao, 2016; Zhao, 2018). Within these systems, students receive standardized instruction that might help them achieve educational outcomes predetermined by national or local educational standards and verified by testing (Zhao, 2016). Research from the learning sciences, education, and other related fields continues accumulating evidence on how humans learn differently (e.g., Cantor et al., 2018). Although the concept of learner variability has gained more traction in recent years, efforts to support such variability are compromised in education systems that center around standardization (Rose et al., 2013). In this regard, education reforms will have little effect unless individual differences and diversity are truly valued in a learning environment that dismantles the culture of normalization (Waitoller & Kozleski, 2013).

Learner Variability

Creating effective learning environments that support learner variability is complex. The complexity is derived from a vast amount of interactions among learners, educators, and other environmental factors. Previous research has shown learner variability in terms of learning ability, metacognition, interest, motivation, linguistic and cultural backgrounds, and/or other factors exists between individuals (i.e., inter-individual variability) and within individuals (i.e., intra-individual variability; Rose & Strangman, 2007; van Geert & van Dijk, 2002).

Because of learner variability, learning activities such as identifying personal learning needs, utilizing appropriate strategies, self-regulating actions, and searching support from learning environments vary across learners and contexts. For instance, learners with varying levels of cognitive abilities, metacognitive skills, and/or motivation may need varying degrees or types of guidance and scaffolding to utilize appropriate learning strategies or engage in learning activities (Cantor et al., 2018). Moreover, brain research has suggested that while between-individual variability related to patterns of brain activity may be distinctive, variability regarding changes of patterns within an individual would remain relatively stable and predictable (e.g., Miller et al., 2002; Rose et al., 2013). Therefore, it is important to proactively consider flexible learning environmental designs that address learner variability and iteratively improve the designs to support emergent learner needs.

Personalized Learning

Research on learner variability helps catalyze the need for transforming standardized approaches to instruction and student learning. Moreover, emergent technologies that make it possible to, among other things, tailor learning and monitor individual students' learning trajectory, which increases the possibility for radical educational reforms. Under this context, many countries have turned to personalized learning (PL) in the hopes of supporting variability and diversity in student learning and, in a broader sense, education systems (Peterson, 2016; Zhang et al., 2020).

For example, in the United States, the latest federal education law, the *Every Student Succeed Act* (ESSA; 2015), mandates that states and local education agencies (LEAs) should use received funds to promote student academic enrichment by providing programs and activities that "increase access to personalized, rigorous learning experiences" (20 U.S.C §

4104A(b)(3)(C)). Specifically, the regulations in ESSA highlight the importance for states and LEAs to address technology readiness needs, use technologies consistent with the framework of Universal Design for Learning (UDL), and support teachers in using data and technology to improve instruction and personalize learning (20 U.S.C § 4106(d)(3)(C)(i)(I-III)). In Finland, many schools are implementing PL to support students in achieving new learning outcome goals, such as communication, critical thinking, and social development (Peterson, 2016). The effort is driven by an initiative to implement a national new core curriculum framework that promotes subject content for more self-directed, authentic, technology-enhanced learning (Peterson, 2016). In 2019, the Chinese government issued an educational development and reform plan entitled, “China Education Modernization 2035 Framework” (Gu & Teng, 2019; Zhu, 2019). The plan highlighted the importance of promoting well-round development, lifelong learning, and personalized instruction to meet learners’ diverse learning and developmental needs (Gu & Teng, 2019).

In addition, recent years have witnessed a surge in researching PL (FitzGerald et al., 2017; Zhang et al., under revision). This leads to a vast body of diverse research investigating PL implementation from across disciplines and countries, situating the phenomenon within divergent theoretical underpinnings and practical domains (Zhang et al., under revision). For example, PL is being researched as a broadly-defined concept (e.g., 1:1 technology-enhanced PL initiative) or practice specifically focused on one aspect of student learning (e.g., mathematics problem-solving activities tailored to learner interests; Bingham et al., 2016; Walkington, 2013).

Nevertheless, a majority of research efforts in the field focused on investigating how advanced technologies could help customize learning content and/or pathways to individual learners (Dishon, 2017). Even within this trend, researchers explored a wide array of emergent technologies, such as intelligent tutoring systems, adaptive assessment systems, ubiquitous technology, and robotics (FitzGerald et al., 2017). A few studies investigated whether human-based practices such as goal setting and choice making benefited students' PL experiences (e.g., DeMink-Carthew & Netcoh, 2019; Netcoh, 2017).

Designing and Implementing PL Supported Through UDL

The lack of common understandings of PL has resulted in confusion in how to operationalize the educational innovation to meet the diverse needs of all learners. The confusion has led researchers and policymakers to different instructional frameworks or models that facilitate better understandings of PL (see Basham et al., 2016; Patrick et al., 2013; Pane et al., 2017). For example, UDL has emerged as such a potential framework for anchoring PL research and implementation. Conceptually, UDL is a scientifically-validated instructional framework guiding intentional designs of flexible learning environments (Rose & Meyer, 2002). To support learner variability, UDL-based environments offer options for engaging in learning activities, comprehending information, and demonstrating understandings for all learners, including students with disabilities and other learners from historically marginalized groups (Meyer et al., 2014).

Accompanying an increasing need for preparing all learners for a rapidly-changing future, UDL as an innovative framework has gained increasing traction around the global education systems (Basham & Blackorby, 2020; Basham et al., in press). For example, UDL is currently referenced in multiple U.S. federal education policies such as the Higher Education Opportunity Act of 2008 and the ESSA of 2015. In addition, 23 U.S. states and the District of Columbia included guidance on integrating UDL into K-12 education in their ESSA plan (Lowrey et al., under review). Beyond the United States, UDL has been adopted at various levels in many other countries, such as Algeria, Australia, Canada, Finland, the Netherlands, New Zealand, Japan, Saudi Arabia, and Singapore (Basham & Blackorby, 2020). Moreover, education policies around the globe are making efforts to meet the fourth United Nations Sustainable Development Goal, which aims to “ensure inclusive and equitable quality education and promote lifelong learning opportunities for all” (Boeren, 2019; United Nations, 2015, p. 21). Under the current global education policy climate, PL and UDL, as emergent educational innovations premised to support all learners, have the potential to contribute to the mission of providing inclusive and equitable education for all.

However, this is a dearth of research investigating PL within the framework of UDL. This project proposed that in a UDL-based PL environment, educators implement UDL to provide tailored learning experiences to individual learners, and learners are empowered to develop self-determination skills for actively participating in learning activities. Specifically, this project highlighted the necessity of building a dynamic relationship balanced between learner autonomy and environmental supports for individual learners in a given learning experience. This argument invites a critical question regarding how to assess whether the relationship is balanced and tailored to individual learners’ needs.

One important means of building the dynamic balance between student autonomy and environmental supports is to involve learners in improvement cycles of examining, shaping, and reshaping their learning experiences. According to Dewey’s educational philosophy, degrees of freedom orchestrated by educators need to center on “supporting students’ capacity to take part in forming the ends of the educational process” (Dishon, 2017, p. 280). Learners who are the causal agent of their learning can engage in self-regulatory and self-management activities that enable them to examine their current state with a goal state and to self-monitor and self-evaluate progress (Shogren et al., 2015). Thus, promoting students' capacity to assess whether the learning environment is designed for their needs is an important way for them to engage in self-monitoring and self-evaluating activities. Through the UDL lens, individual learners may encounter different barriers within the same context or across contexts (Basham & Marino, 2013). In this regard, there is a need to iteratively detect context-specific barriers through the eyes of each individual learner, which helps identify areas of design failure where corresponding improvements can be introduced.

Assessing UDL-Based PL from Learner Perspectives

The implementation of UDL was measured differently across the existing studies, which poses challenges to operationalize UDL-based practices that support students' learning experiences (Basham et al., 2020). Students, as assessors of learning experiences, have the potential to provide critical information on whether the design of learning environments meet their needs. Students who have the first-hand experiences of interacting with peers, teachers, and other environmental factors are able to "articulate the main influences on their educational engagement and achievement in school and make suggestions as to how teachers could create classroom contexts that would be more conducive to learning" (Kane & Maw, 2005, p. 319).

A considerable amount of research has reported positive links between students' self-ratings of learning experiences or classroom climate and their educational outcomes (e.g., Lüdtke et al., 2009). Additionally, previous research has shown that students' perceptions and beliefs influence their capacity and opportunity for developing such self-determination skills as choice making, goal setting, self-regulating, and self-advocacy (Wehmeyer & Mithaug, 2006). Attending to student perspective and soliciting their input is regarded as a foundational element of promoting autonomy support for increasing student volitional functionings (Reeve, 2009).

Effective integration of student perception into the classroom assessment system may increase more desirable learning environment designs, which, in turn, helps foster more autonomy and agency in classrooms (Mäkelä, 2018). Therefore, ongoing assessment of whether and how learning environment designs work across individuals and contexts from learners' perspectives is needed for the design, implementation, and measurement of PL.

Statement of the Problem

As discussed above, PL is conceptualized as a broad education effort aiming to increase access to equitable learning experiences for all learners, including students with disabilities and other students from historically marginalized groups. However, there is a lack of consistency in PL conceptualizations, which has resulted in confusion among researchers and practitioners about how to implement PL. As a scientifically valid framework, UDL could help dissolve the confusion by providing foundational design and implementation considerations for PL. To support this argument, there is a need to investigate how UDL could provide guidance on the design and implementation of PL experiences for all learners. In line with the premise of UDL and PL to promote student agency, supporting students in assessing their learning experiences has the potential to empower them to participate in the design of their UDL-aligned learning environment. This argument is appealing but yet untested. One challenge is that to date there are no measures that can be used to solicit students' perceived learning experiences and evaluate the extent to which their experiences are supported by UDL environmental designs.

Purpose and Structure of the Dissertation

The purpose of this dissertation was to explore the design, implementation, and measurement of PL environments through the lens of UDL. This dissertation prioritized three steps in order to achieve its proposed goals: (1) conceptualize PL designs through the lenses of

UDL and increased student autonomy; (2) investigate the extent to which PL implementation practices emerging from the current literature align to the UDL framework; (3) develope a student self-report instrument that can be used to assesses student learning experiences in an environment designed according to the framework of UDL. Specifically, this dissertation consists of five chapters, which are discussed briefly as follows:

Chapter One introduced the problem, purpose of the dissertation project, and a brief overview of each chapter. This chapter briefly described the concepts of learner variability, PL, UDL, and learning experience assessment. The way these concepts interacted to address the purpose of this dissertation project was discussed. This chapter concluded with a discussion of the significance of the project.

Chapter Two discussed a conceptual framework that supports the design of PL. The framework ties together research on UDL and self-determination. Based on the framework, an autonomy-supportive mechanism was proposed to facilitate the design of PL. The structure of this chapter is as follows. In the first section, I argued for establishing an inclusive, PL environment for all learners as a means to dismantle educational inequalities. This argument began with critically analyzing issues associated with educating students with and without disabilities in standards-focused learning environments. Then, I elaborated on how historical contexts in which standardization in educational institutions influenced practices and research on educational practices for diverse learners. Underlying the analysis is a need to reconceptualize educational practices through a lens of supporting learner variability in PL environments.

To address the need, I detailed two arguments for establishing PL environments: 1) implement UDL as a framework that guides the design of PL environments to meet the diverse needs of all learners and 2) support students in developing self-determination skills needed for thriving in PL environments. This chapter offered implications for research on how to build an autonomy-supportive mechanism that facilitates the implementation of UDL-based PL. Additionally, this chapter set the stage for the next two chapters, the purposes of which were to explore empirical evidence on UDL-aligned PL designs and developing an instrument for measuring student learning experiences within PL environments, respectively.

Chapter Three reported on an updated synthesis of the research on PL conducted between 2006 and 2019. Guided by the complex dynamic systems perspective of human learning, this synthesis integrated the current empirical PL practices onto the framework of UDL. The results showed that across the existing studies student learning was often personalized in a narrow sense. From the lens of UDL, only a few studies illustrated relatively comprehensive PL designs that have the potential to better support dynamic learning for all students. This chapter ended with discussions around learner variability, the role of technology, and data use in PL implementation as well as associated implications for policy, research, and practice.

Chapter Four discussed a conceptual framework and its application in developing a practical instrument for measuring student learning experiences in UDL-based learning environments. To conceptualize the need for developing such an instrument, I stressed that student voice should be incorporated into the measurement system that assesses complex, student-centered, PL environments. I then proposed that assessing students' learning experiences could serve as a potentially powerful means to measure UDL implementation by gauging whether UDL-based designs meet the diverse learning needs of all learners. Afterward, this chapter provided a detailed description of the instrument development, which was guided by research on learning environment assessment and UDL. This chapter then reported on a study investigating the evidence for the content validity of the instrument. Implications and future directions for validating and using the created tool in practices and research were discussed.

Chapter Five concluded the dissertation project by providing implications for future research on the design, implementation, and measurement of PL through the lens of UDL. In particular, this chapter provided implications for future PL research and practice considering the current circumstances facing the global education system. Additionally, highlighting the importance of supporting learner agency and autonomy in PL environments, this chapter provided implications for research and practice pertaining to the effective use of student feedback on instructional designs to inform improvement in the design of PL.

Contribution and Significance of the Dissertation

The dissertation project is conceptually and practically significant in improving understandings of how to apply UDL to PL research and practice as well as providing a practical tool that can be used to support and monitor the PL implementation processes. First, this project provided conceptual and empirical analyses for designing and implementing PL supported through UDL. Analyzing effective PL designs based on theoretically and empirically validated models, such as UDL and self-determination in this project, is critical to advancing the field's common understandings toward research and practice. Second, the project presented an effort to develop a student learning experience instrument. The instrument was designed to support students in evaluating whether the design features of a UDL-based learning environment meet their learning needs. Teachers can use those perception data to identify areas of improvement in instructional designs. Incorporating the student instrument into data use system also allows implementation teams to assess the quality of systematic implementation of UDL in classrooms, expanding the evidence of the framework.

To conclude, this dissertation project illustrates an explicit framing of the concept of UDL-based PL, analysis of evidence for UDL-based PL designs, and effort of developing the instrument for measuring learning experiences as a means to inform continuous learning environmental designs. Situating PL within the UDL framework is particularly merited given increasing demands on implementing UDL to support all learners around the globe.

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Chapter Two: Balance Learning Designs Guided by UDL and Learner Autonomy in Personalized Learning Environments

In this chapter, I argued for establishing an inclusive, personalized learning (PL) environment for all learners as a means to dismantle educational inequalities. This argument began with critically analyzing issues associated with educating students with and without disabilities in standards-focused learning environments. I elaborated on how historical contexts in which standardization in educational institutions influenced practices and research on educational practices for diverse learners. Underlying the argument is a need to reconceptualize educational practices from a lens of supporting learner variability and individual development in PL environments. Specifically, I detailed two arguments that support the establishment of PL environments: (1) Universal Design for Learning (UDL) applied as a framework for designing PL environments that meet the diverse needs of all learners and (2) students developing self-determination skills to thrive in PL environments. Building a bridge between the two concepts, an autonomy-supportive mechanism was proposed to serve as a driver to advance the development of and research on PL. Implications for research and practice with a focus on implementation and assessment of PL were discussed.

Historical Context: Ineffective but Efficient Education Systems

Assumption of the Average Learner

Over a century ago, Belgian statistician Adolphe Quetelet constructed the notion of the average man and justified the application of normalcy to signify what conforms to or deviates from the “true mean” of human attributes (Davis, 1995; Rose, 2016; Shogan, 1998). While Quetelet considered the average as how things ought to be and the deviations as errors, another statistician Francis Galton viewed the average as an indicator of mediocracy requiring improvement and thus developed an idea of rank to sort people into different ability groups from low to high (Rose, 2016; Shogan, 1998). Today, Quetelet's idea of the average man and Galton's idea of rank still serve as the operational principles behind almost all contemporary education systems (Rose, 2016).

For instance, influenced by the notion of average, educational organizations in the United States had begun to apply to their structures and practices since the early 1900s the principles of scientific management, which were introduced by John Franklin Bobbitt to secure standardization and efficiency of factory production (Au, 2011; Skrtic, 1991; Sullivan, 2005). Moving toward an efficient, means-ends rationalized managerial system, school organizations operate like machine bureaucracies, where teachers have to compromise their discretion to personalize instructional practices to the particular needs of their students while complying with rules and regulations (Skrtic, 1995). Students in standards-based education systems end up receiving instruction for a prescribed, uniform set of knowledge and skills predetermined to be necessary for a successful future career and life (Zhao, 2018a; Zhao et al, in press).

Galton's idea of rank is also embodied in the meritocracy mindset prevailing in most existing education systems (Allen, 2011; Zhao, 2016). Such a mindset pushes schools to utilize intelligence testing and other psychometric techniques to measure students' abilities and then pigeonhole them into different groups accordingly. The consequences of pigeonholing are profound. It prevents schools from problem solving and innovation when students' needs do not match teachers' repertoire of skills, resulting in forcing students artificially into one of the available standard practices (Skrtic, 1995). Each pigeonholed group is tied to certain interventions performed by professionals and experts, who attempt to norm the "nonstandard" (Shogan, 1998). On the one hand, standardized instructional practices with pigeonholed groups help maintain stability and efficiency in schools as well as ensure the place of professional specialists and their access to decision making (Shogan, 1998; Sullivan, 2005; Weatherly & Lipsky, 1977). On the other hand, those practices also successfully impede learner diversity and alienate them from their own creativity and intellectual curiosity (Au, 2011; Zhao et al., in press).

Ineffective Instruction in Standardized Education Systems

Standardization neglects dynamic development for learners with diverse needs. As standardized instructional designs and approaches fail to address students' diverse needs, pathological or medical perspectives of learning diversity evolved and demanded special education services be delivered to students labeled with specific "deficiencies" (Skrtic, 1995; Lipsky & Gartner, 1997). The standardized practices in education had driven the segregation of students whose diverse learning needs were considered to deviate from the "norm" and need to be fixed (Davis, 1995). The sorting mechanism based on the assumption of normal distribution and meritocracy divided education into general education and special education (Lipsky & Gartner, 1997).

Both standards-driven model of education and deficit-driven model of learning difference reinforced by legislation pushes for accountability, have greatly impacted practices and research in the field of (special) education (Cochran-Smith & Dudley-Marling, 2012; Diamond, 2007; Skrtic, 1995; Zhao, 2016). The movements for school accountability have continued to drive more top-down control of schools and classroom practices (Au, 2011; Darling-Hammond, 2010). On the one hand, the accountability systems have incentivized teachers to use more rigorous pedagogical approaches to enhance student learning outcomes; on the other hand, they exacerbated educational inequalities by marginalizing students who could not fit into the systems (Diamond, 2007).

Educational practices under the standards-based context are designed to fix students rather than to redesign the ineffective educational system (Zhao, 2018a). Under the mandates of educational legislation and ongoing inclusion movements, more students with disabilities have access to general education classrooms (Artiles & Kozleski, 2016). However, if education, especially special education, moves its disciplinary base away from the exclusively biological or medical model of learner difference, a substantially different framework of theoretical, applied, and practical knowledge to address the ineffectiveness of education would be introduced (Skrtic, 1995).

Personalized Learning: A Potential Solution?

In the last two decades, personalization has emerged as a response to end the industrial mass production model of delivering public services (Peters, 2009; Rose & Ogas, 2018). In the field of education, PL or personalization in learning has gained increasing traction as a means to customize learning to individual needs, with the premise to drive education systems away from the "one-size-fits-all" model (Redding, 2016). Other similar concepts such as personalized education (e.g., Peterson, 2016) and personalizable education (e.g., Zhao, 2018b) have also appeared in research reports and/or books discussing education reforms. Although researchers in the field have discussed the difference between PL and other terms such as personalizable education (see Zhao, 2018b), PL or personalization in learning will be used throughout this dissertation to broadly refer to the education reform efforts of tailoring learning experiences to individuals' interests, preferences, and/or needs.

Ambiguous Concepts of PL

Increasing globalization and digitalization of society have incentivized governments, organizations, and researchers across the globe to turn to PL to modernize or innovate the education system (Peterson, 2016; Zhang et al., 2020). Although differing in forms, efforts to reform education call for a radical change so that education system can move from mass production and standardization to mass customization and personalization (Peters, 2009). As a complex educational innovation, PL is still in its infancy; therefore, it is not surprising that there is a lack of a shared definition or understanding of how to implement the innovation. As it is widely, but ambiguously conceptualized, PL is built on an understanding that tailoring instruction and learning to individual students' unique interests, personal preferences, and/or specific needs can help make learning relevant, meaningful, authentic, and self-initiated (Patrick et al., 2013).

A recent literature review of PL found that researchers from different fields of study such as education, the learning sciences, and computer science investigated the implementation of PL from different aspects (Zhang et al., in press). The emergent research trends identified in the review include, but not limited to, investigation of technology-enhanced practices and/or systems that supported personalization in learning content, materials, feedback, and/or paths as well as school-level initiatives that facilitated teacher-learner interaction, goal setting, or choice making as ways of increasing students' PL experiences. Under a broad PL conceptualization, the wide array of research investigations varied in aspects of PL designs or depth of students' PL experiences.

Advocates for PL vision that the emergent educational innovation provides solutions to the intractable problems produced by standardized educational practices (Redding, 2016). Yet, the alarming transition from a standardized to a personalized system is an intractable problem itself that deserves careful investigations in the early stage when efforts are made to develop models for operationalizing PL. The intractability first derives from the fact that personalizing learning or education requires a variety of transformations in the form of, among other things, new core curricula, flexible but rigorous outcome goals, and competency-based assessments (Peterson, 2016). For example, when it comes to curriculum reform, the problems remain as to how to implement new core curricula that outline not only content and skill standards but cross-curricular such as technology literacy, communication, critical thinking, and other transversal or 21st-century skills. Each form of personalization involves complex procedures needed for changing entrenched practices in traditional education systems.

The role of Technology for PL

The current conversations around how to radicalize education systems through PL is closely tied to advanced technologies, which have been touted as a powerful tool to efficiently customize and deliver personalized experiences to individual students (e.g., Abbott et al., 2014; Chen, 2009; U.S. Department of Education, 2017). Many countries such as the United States, the United Kingdom, South Korea, and Finland have issued national education policies to promote PL supported by technology for all learners as a means of preparing for an inclusive future citizenry (Basham et al., in press; Peterson, 2016). Additionally, this emerging trend can be found in the current literature on PL, the majority of which emphasized the indispensable role of technology such as adaptive learning systems, mobile learning systems, or school-wide 1:1 technology initiatives in implementing PL (Zhang et al., in press).

Technology-enhanced PL is usually advocated to hold the potential to adapt learning to individual needs by capitalizing on a large quantity of real-time data from complex learning processes in naturalistic learning environments (Dishon, 2017; Basham et al., 2016). Indeed, technological advancements are and will continue transforming teaching and learning experiences, opening up opportunities for personalization. Alongside the surge of research on technology-enabled PL, there arises a debate about whether various PL platforms operating on learning analytics and/or data mining techniques truly fulfill the progressive vision of PL, that is, making learning more relevant and self-initiated (see Bulger, 2016; Dishon, 2017). Central to the debate is a discussion on whether and how PL supports more student autonomy and agency over their own learning (Dishon, 2017).

Learner Agency in PL

Advocates for PL posit that if implemented effectively, the innovation can help fulfill Dewey's theory of progressive education, which emphasizes experiential, learner-centered, and social learning as well as preparation of democratic citizenry for a changing world (Redding, 2016). According to Dewey (1916), education should empower students to continually reorganize and reconstruct learning experiences and ends, enabling them to become meaningful shapers of their educational process. Enhancing student autonomy and agency over learning, thus, is conceptualized in many educational policies and research reports as an essential aspiration of PL (e.g., Patrick et al., 2013; Robinson & Sebba, 2010; U.K. Department for Education and Skills, 2005; U.S. Department of Education, 2017).

For example, in the article *Choice and Voice in Personalised Learning*, Miliband (2006) highlighted the concepts of “choice” and “voice” as fundamental to PL. He posited that student voice can help shape the provision of choice, “both as a means of engaging students in their own learning—the co-producers of education—and as a means of developing their talents—using their voice to help create choices” (Miliband, 2006, p. 30). Patrick and colleagues (2013) also pointed out that PL should enable student choice and voice in determining what, how, when, and where to learn, thus providing flexibility and supports to help them reach their greatest potential. More importantly, previous research has shown that choice can enhance intrinsic motivation, effort, and task performance (e.g., Patall et al., 2008). Yet, it is equally important to note that students are likely to feel less competent or engaged in an environment profuse in choices (Evans & Boucher, 2015). A previous case study indicated that profusion of choice in a PL environment demotivated some students (Netcoh, 2017).

Enhancing learner autonomy and agency in PL environments faces inevitable challenges. First, traditional education systems designed with fixed and predefined means and ends of teaching and learning limit flexibility for educators to provide choices. Even granted with opportunities to provide choices, it is challenging for educators to balance choice and academic rigor for individual learners in learning environments (Netcoh, 2017). Furthermore, students may be oblivious of how their choices are structured (Dishon, 2017). Or, appropriate support is inaccessible to them to make choices that fit their needs and interests. These challenges indicate that there should be a supporting mechanism that facilitates mutual influence in shared decision making among learners, educators, and other stakeholders.

Emerging Questions Regarding PL Models

The premise of PL—either in face-to-face, blended, or online modality—cannot be achieved unless effective implementation models for the innovation are developed, tested, and refined. The very strength of establishing a PL model or environment is the focus on accepting and supporting student variability through varied, well-designed learning activities toward an end goal (Zhang et al., in press). Aligned to Dewey's perspective of child-centered, progressive education, such an end goal may vary across individual students (Dewey, 1939). Simply put, human learning is a complex process; therefore, building supporting models for PL needs to take into consideration of varied school, classroom, and student level factors that help promote individual students' optimal learning experiences.

Thus, what is needed in the field is more research investigating PL models that support effective interactions between individual learners and their learning environment, which, in turn, lead to increased educational outcomes for all learners. Then, questions arise as to what instructional designs are considered effective in meeting individual learners' needs in a PL environment? What roles do educators and learners need to play in creating better PL experiences? What measures can be used to examine the effectiveness of PL learning environment designs? To address these questions, I introduce the concepts of UDL and self-determination as two essential elements of a supporting model for PL in the next section.

Conceptual Framework

This chapter presents an initial effort to explore a supporting model for building PL based on UDL. The model is premised on applying UDL to designing learning environments and promoting learners' self-determination skills to navigate the corresponding environments. The foundational principle of the model is to support *learner variability* in PL environments.

Utilizing UDL as A Framework to Guide PL Designs

UDL is an instructional design framework that resists deficit views of learners with diverse needs and values diversity in how each individual learns in a given context (Meyer et al., 2014). The basic premise of UDL is to value diversity and redesign ineffective learning environments so as to fix the mismatch between environmental support and learner capacity (Dockterman, 2018). Central to the application of UDL is to dismantle unnecessary barriers to learning and build flexibility in learning environments to adjust to individual learners (Rao & Meo, 2016). To contextualize the argument of using UDL to anchor the design of PL, the following subsections briefly describe the history, theoretical underpinnings, and implementation considerations of UDL as a design framework.

Basic concept. The concept of UDL, developed by David Rose, Anne Meyer, and colleagues at CAST, was considered as an extension of the *universal design* movement in architecture initiated by researchers at North Carolina State University College of Design (Edyburn, 2010; King-Sears, 2009). The aim of universalization is to make environments, services, and products including assistive and other forms of technology accessible to and usable by the widest spectrum of users (Rose & Meyer, 2002). When applied to education, the concept is commensurate with a major paradigm shift, that is, increasing access to learning environments (both physically and cognitively) and providing universal learning experiences for students with and without disabilities in general education settings (Edyburn, 2010).

Policy foundation. Since its introduction into education, UDL has been advocated as a reform effort to promote inclusion through system change (Hehir, 2009). In the United States, different federal education laws have supported this effort. For example, the regulations of the Individuals with Disabilities Education Act (IDEA) of 1997 and 2004 emphasized enhancing access to the general education curriculum for students with disabilities through assistive technology; this endorsement opened possibilities for inclusion based on the UDL framework (Hehir, 2009). Under the section 3 of the Assistive Technology Act of 1998, Universal Design is defined a "concept or philosophy for designing and delivering products and services that are usable by people with the widest possible range of functional capabilities." Because of this close tie with technology, universal design is always referenced as the principles for designing instructional technology or assistive technology to maximizing accessibility to the general education curriculum for students with disabilities in IDEA (i.e., 20 U.S.C § 1411(e) (2) (C)).

The early definition and references in the U.S. education law made UDL often mis-conceptualized as a form of assistive technology. As understandings, implementation, and research advanced, UDL has been increasingly acknowledged as a design framework fundamentally about proactively valuing diversity (Basham & Blackorby, 2020). Its implementation is effectively, but not exclusively, built upon technology (Edyburn, 2010). Later, the Higher Education Act (HEOA) of 2008 was the first U.S. federal legislation to endorse UDL as a scientifically valid framework for guiding inclusive educational practices and highlight the importance of incorporating the framework into teacher preparation and training. Most recently, the Every Student Succeeds Act (ESSA) of 2015 recognized UDL as foundational for designing high-quality inclusive, student-centered, PL environments for all learners (Basham et al., 2018).

Research foundation. The development of UDL is grounded in research from neuroscience, learning sciences, cognitive psychology, pedagogy, and instructional design, and technology (CAST, 2018a). The framework of UDL is predicated upon the variability inherent in three neurological networks—affective, recognition, and strategic—that influence how humans learn. The neuro-variability explains why humans differ in how they engage in activities, perceive and comprehend information, as well as navigate a learning environment and express what they know (CAST, 2018a; Rose & Meyer, 2002). The UDL framework, organized around three principles accordingly, is premised on providing multiple means of engagement, multiple means of representation, and multiple means of action and expression to support the neuro-variability within and between learners (Meyer et al., 2014). The three principles further provide insights into learner variability in nine fundamental areas including interest, effort and persistence, self-regulation, perception, language and symbols, comprehension, physical action, expression and communication, and executive function. Based on research behind these areas, CAST created the UDL Guidelines consisting of nine guidelines and 31 associated checkpoints, along with detailed descriptions and examples of how they can be operationalized in instructional and learning environment designs (CAST, 2018b; Rao et al., 2014).

To date, a considerable body of research has investigated how UDL-based practices impacted educational outcomes for students with and without disabilities (e.g., Basham et al., 2010; Coyne et al., 2012; King-Sears et al., 2015; Marino et al., 2014). Ok and colleagues (2016) conducted a systematic literature review of 13 intervention studies that investigated applications of UDL to curriculum and instruction in PK-12 educational settings. Overall, the results showed that UDL-based interventions hold the promise for addressing learner variability and increasing access to the general education curriculum.

Nevertheless, Ok and colleagues (2016) found that UDL principles were applied in varying ways in these studies, with some examining technology-based learning environments with built-in UDL-aligned features and others investigating the use of instructional methods based on UDL. In addition, the degree to which components of these interventions linked to UDL guidelines and checkpoints varied greatly (Ok et al., 2016). For instance, in two quasi-experimental studies, Marino et al. (2014) and King-Sears et al. (2015) detailed how the features of four science video games or chemistry curricula were designed in alignment with various UDL checkpoints, respectively. Whereas Marino et al. (2014) discussed UDL-aligned features such as offering choices and alternative assessment to students, providing animated tutorials, and integrating pictorial and verbal instruction, King-Sears et al. (2015) focused on a self-management strategy that incorporated all three UDL principles. In another study that used design-based research methodology, Basham and colleagues (2010) investigated how students engaged in project-based learning through which they had access to learning materials in multiple formats, chose their own roles in groups, self-regulated learning process, and expressed understanding of freedom through a final project of choice.

Interdisciplinary and evolving framework for design. The UDL framework started as a response to the need for increasing access to general education curriculum for students with disabilities; now it has grown to recognize engagement and motivation as central for learning across learners and subjects in modern education systems (Basham & Blackorby, 2020). With its genesis grounded in interdisciplinary research, UDL continues to evolve as an interdisciplinary design framework drawing upon advances in relevant research that explain and support learner variability (Meyer et al., 2014). Although frequently mentioned in policy documents, theoretical articles, and research reports on empirical evidence behind each UDL checkpoint, the implementation of UDL still faces confusions and challenges.

Partially, the confusion might arise out of misunderstanding UDL as a practice, intervention, or program (Basham & Blackorby, 2020). In reality, as its name suggests, UDL is fundamentally about *design* (Edyburn, 2010). The UDL Guidelines provide basic considerations for designing flexible learning environments with options and scaffolds that address predictable learner variability (Basham & Blackorby, 2020). As barriers emerge from interactions between individual learners and their environments in a given context, the framework can guide educators to find, test, and refine a design solution through iterative processes. In this sense, the application of UDL in designing for all learners may vary across contexts because of the variability in both learners and learning environments.

When integrating flexibility in representation, action and expression, and engagement, UDL-based learning environments acknowledge and foster the uniqueness of each learner so that all learners have opportunities to maximize their strengths, drive their own learning processes, and become expert learners (CAST, 2018a). However, it is also this varying and flexible application that gives rise to confusion as to what constitutes or in what combination the principles or guidelines need to be present for a design to be considered as universal and effective (Ok et al., 2016; Rao et al., 2014). Furthermore, given that the implementation of UDL is contextualized, the concept itself is still a living concept evolving as a result of ongoing interactions among researchers, educators, and learners across contexts (Basham & Blackorby, 2020; Meyer et al., 2014).

Implementation considerations. Although UDL implementation is highly contextualized, researchers identified clear goals, intentional planning for learner variability, flexible methods and materials, and timely progress monitoring as four critical elements of UDL implementation (UDL-IRN, 2011). To drive both proactive and iterative designs, researchers suggested that UDL implementation follows a problem-solving process premised on data-based decision making (Basham et al., 2010). Because UDL can be applied in a multitude of ways, problem-solving processes vary across contexts. In any process, nevertheless, both educators and learners need to actively participate as core stakeholders in identifying and solving problems existing and emerging from learner-environment interactions. As one of fundamental premises of UDL is to support expert learning (Meyer et al., 2014), questions regarding what means to be an expert learner and what supports all learners in becoming expert learners deserve careful investigation.

Students Developing Self-determination to Succeed in PL Environments

Personalization in learning or in a larger sense in education systems promotes learner agency, shared ownership, and flexibility in how students achieve end learning goals (Zhao, 2018a). Hypothetically, a PL environment designed according to UDL provides support and choices regarding what to learn, how to learn, and how to demonstrate the learning. An emphasis on personalization in terms of providing multiple choices and/or pathways embedded in the learning environment should drive a shift from educators taking the solo responsibility to design the environment for students to co-designing with educators. This co-designing process will involve all students in sharing control of their own learning and developing skills such as self-advocacy, self-regulation, self-evaluation, and other self-determination skills needed to make appropriate choices, set goals, and take actions to achieve the goals (Wehmeyer, 2019). Therefore, an ideal UDL-based PL environment should balance the provision of choices and promotion of students' decision making and agency. In this section, I briefly review previous research on self-determination, highlighting the importance of providing environmental supports for promoting students' self-determination skills in PL environments.

Theoretical underpinnings of self-determination. Self-determination is conceptualized as a dispositional characteristic with which people act based on their own mind (Deci & Ryan, 2002). Self-determination theory (SDT) investigates people's inherent growth tendencies as well as how humans are motivated to fulfill three basic psychological needs for autonomy (i.e., feeling a sense of autonomous motivation), competence (i.e., feeling capable and competent), and relatedness (i.e., feeling a sense of belonging; Deci & Ryan, 2002; Wehmeyer, 1997). SDT is deeply grounded in research on motivational psychology, which has shown that choice, acknowledgment of feelings, and opportunities for self-direction allow people a greater feeling of autonomy that leads to enhanced intrinsic motivation (Deci & Ryan, 1985).

In addition to intrinsic motivation, SDT explores the processes through which non-intrinsically motivated behaviors can become truly self-determined and the ways the social environment influences those processes (Deci & Ryan, 2002). Particularly when social environments are supportive of people driving toward action to address basic psychological needs, their overall well-being is enhanced (Shogren et al., 2015). It is also important to note that social-contextual conditions contribute to differences in motivation and personal growth both within and between persons (Ryan & Deci, 2000). These differences result in people being more self-motivated and engaging in some situations than in others, which bears implications for “the design of social environments that optimize people’s development, performance, and well-being” (Ryan & Deci, 2000, p. 68).

Drawing upon motivational psychological and educational literature, Wehmeyer (1992) defined self-determination as “the attitudes and abilities required to act as the primary causal agent in one’s life and to make choices regarding one’s actions free from undue external influence or interference” (p. 305). Furthermore, Wehmeyer and colleagues developed the functional theory of self-determination that views self-determined behaviors, which include autonomy, self-regulation, psychological empowerment, and self-realization, as functions enabling individuals to act as the causal agent in their lives and to act volitionally (Wehmeyer et al., 2003). Since then, considerable research has validated the functional model of self-determination and investigated the efficacy of different interventions developed through the functional model on improving self-determination skills for students, especially students with disabilities (e.g., Shogren et al., 2011; Wehmeyer et al., 2012).

Afterward, Wehmeyer and colleagues proposed the Causal Agency Theory as an extension of the functional model of self-determination drawing on advances in positive psychology (Wehmeyer & Mithaug; 2006). Causal Agency Theory places an emphasis on self-determined actions rather than behaviors (Shogren et al., 2015; Wehmeyer & Mithaug, 2006). The theory explains how and why people become self-determined and represents specific layers of human agency that “fall in between the drive to meet basic psychological and biological needs and the agentic self” (see detailed description in Shogren et al., 2015, p. 258). Within the context of Causal Agency Theory, self-determination actions are characterized by volitional action, agentic action, and action-control belief, concerning the extent to which “behavior is volitional and agentic, driven by beliefs about the relationships between actions (or means) and ends” (Shogren et al., 2015, p. 258). Volitional action enables people to make conscious choices based on their values, beliefs, and references. Agentic action enables people to proactively and purposefully identify pathways that lead to a specific end or cause, create change, and respond to opportunities and challenges in their environments. Action-control belief functions to help people act with self-awareness and self-knowledge in an empowered, goal-directed manner.

Improving self-determination for all learners. Numerous research has also proven the links between enhanced self-determination skills and positive educational outcomes, especially for students with disabilities (e.g., Cobb et al., 2009; Wehmeyer et al., 2012). Nevertheless, all learners need opportunities to engage in choice making, problem solving, decision making, goal setting and attainment, self-regulation, self-advocacy, and self-awareness activities to cultivate self-determination skills across diverse social-contextual contexts (Shogren et al., 2015). Particularly, researchers suggest that instruction to promote self-determination might be more effective if provided across instructional activities for all learners in inclusive educational settings (Shogren et al., 2016).

The self-determination skills described above are highly valuable for all learners to thrive in a PL environment. As a basic consideration for a PL environment is to integrate a wide array of supports including tools, resources, and strategies, all learners need to be empowered with a greater autonomy over the design of their learning and educational services. Meanwhile, within a

PL environment that highlights learner variability, learners will need diverse, tailored supports to access both physical and psychological learning environments. The ultimate goal of these supports is to promote positive academic, social, and behavioral outcomes for all students, preparing them to become purposeful, resourceful, and goal-directed learners (Meyer et al., 2014).

Taken Together: Building An Autonomy-Supportive Mechanism for PL

This dissertation project situates PL within the UDL framework that guides educators in creating flexible learning environments. In such environments, students with diverse needs have access to choices and need to enhance agency over their learning through improved self-determination skills. Providing choices is not tantamount to granting students unlimited freedom by removing any structure from learning environments or any support from teachers. Variations in the degree to which individuals successfully navigate through the environments and participate in self-determination actions would emerge based on the level of environmental supports (Shogren, 2006). Additionally, not all learners are equally capable of assessing both the demands of the task and their own learning needs in order to choose appropriate strategies for effective learning when the locus of control of learning is completely placed within learners (Kirschner & van Merriënboer, 2013).

Therefore, balancing autonomy and support for each individual learner through a dynamic autonomy-supportive mechanism is an important step to better understand how to design, develop, and implement PL environments. In this chapter, the term mechanism is used to explain interdependent relationships among components of a system (e.g., a PL environment) and the characteristics emerging from their interactions (Hedstrom & Swedberg, 1998). The term "autonomy-supportive" or "autonomy support" is often referred to in the literature on self-determination and/or motivation as interpersonal sentiment and behavior teachers provide during instruction that promotes students' volitional functioning (see Reeve, 2009; Vansteenkiste et al., 2004; Vansteenkiste et al., 2012).

Specifically, Reeve (2009) identified three conditions that enable teachers to create autonomy-supportive learning environments. These conditions include (1) adopting the students' perspective, which enables teachers to become more able to create classroom activities aligned to students' autonomous motivation; (2) welcoming students' thoughts, feelings, and actions, which enables teachers to acknowledge the motivational potential inherent within students; and (3) supporting students' motivational development and capacity for autonomous self-regulation, which enable teacher-student interactions to revolve around both daily and long-term supports for academic and motivational pursuits.

From an applied perspective, teachers can adopt an autonomy-supportive approach by building in choices whenever it is possible, allowing for self-paced learning, nurturing intrinsic motivational resources, providing rationales for expectations, attending to students' voices, using uncontrolling language, and accepting expressions of negative affect (Reeve & Halusic, 2009; Vansteenkiste et al., 2012). To a large extent, these strategies align to the suggested practices that fit under the UDL principle—providing multiple means of engagement (CAST, 2018a). Yet, the autonomy-supportive mechanism proposed in this article goes beyond merely promoting engagement. In line with the fundamental goal of UDL, a dynamic autonomy-supportive mechanism in UDL-based PL environments should facilitate authentic, challenging, goal-oriented learning processes. These processes may differ within and between individual learners due to variations in learners' interest and engagement, perception and comprehension, and action and expression. Hypothetically, an ideal outcome from promoting such a mechanism is that all learners will become more capable to actively co-design their PL experiences in diverse settings, thus becoming self-determined, expert learners. As such, more research is needed to test the hypothesis.

Discussion: How to Move Forward?

The purpose of this chapter is to present a conceptual framework that guides the design of PL environments to support all learners. The conceptual framework is situated at the intersection of implementing UDL and promoting student self-determination. To provide environmental supports, the implementation of UDL is premised to build flexibility, choices, and scaffoldings in learning environments to improve learning experiences for all learners. One way to determine whether environmental supports meet individual students' needs is to actively involve students in the processes of designing, measuring, and improving their own learning experiences. Increased student involvement and participation will provide more opportunities for learners to develop self-determination skills needed for thriving in PL environments. Drawing upon these considerations, this chapter proposed a dynamic autonomy-supportive mechanism to support individual students' learning needs in a PL environment.

Understanding how to build the dynamic mechanism based on UDL and self-determination serves as a starting point to investigate effective PL models that address individuality in learning for all learners. To date, extensive research has investigated the implementation of UDL and learning models that promote student self-determination, respectively (e.g., Marino et al., 2014; Ok et al., 2016; Shogren et al., 2011). More research is needed to investigate how UDL-based PL environments facilitate and promote student self-determination; and vice versa how increased self-determination benefits the establishment of

UDL-based PL environments. Either way, researchers and implementers should have access to useful information that effectively balances between environmental supports and learner agency.

Current Issues and Considerations for Future Research

This chapter suggests a potential avenue for future research to look at effective ways to measure the fit between the UDL-based PL environmental supports and individual learner needs. The information on the fit, or lack thereof, can be used to guide decision-making processes regarding whether and what environmental supports need to be adjusted to better support learning for all students. It is important to acknowledge that measuring the effectiveness of UDL-based environmental supports is complex. As a complex design framework, the implementation of UDL has been measured in a variety of ways across the existing literature (Evmenova et al., 2018). The lack of consensus on to measure UDL implementation poses questions as to how to measure whether UDL-based environmental supports or designs meet the learning needs of individual learners in within PL.

To address the challenge, there are several considerations for the future research. First, the core premise of UDL is to support expert learning, which is "always a process of continuous learning–practice, adjustment, and refinement" (Meyer et al., 2014, p. 24). The continuous learning processes are variable for individual learners. As a result, measuring the complex UDL environment supports requires accurate and timely analyses of an enormous amount of information on individual learners' psychological and behavioral responses to the supports. Additionally, student learning experiences are influenced by contextualized factors specific to classroom, school, and/or district improvement goals. This means that future research can focus on developing measurement systems that make data available on individual students over time and support looking at data associated with learning growth from multiple sources.

Advancing the measurement of complex learning design processes requires advanced data systems. Currently, researchers have attempted to integrate machine-generated and human-provided assessments into advanced online data systems to capture and model complex, dynamic individual learning processes (e.g., D'Mello et al., 2017). For example, assessment tools using digital sensors to capture learners' facial features, behavioral movements, and other physiological signs have potential to capture fine-grained learning responses of individual learners to environmental supports. Data collected through human-provided assessments such as self-reports and observer ratings can provide information on human judgements of learning processes. When data from multiple sources are modeled, longitudinal analyses (e.g., growth curve modeling) can illustrate how individual learner interact with environmental supports over time. Measuring UDL environmental supports can benefit from an integrated measurement system that guides the design, delivery, and evaluation of individual learning experiences.

In particular, this chapter highlighted the importance of empowering learner voice in the design of learning environments and improving access for all learners to evaluate whether their learning learnings are met. A considerable amount of research has reported positive links between students' self-ratings of learning experiences or classroom climate and their educational outcomes (e.g., Kane & Maw, 2005; Lüdtke et al., 2009). Learners with first-hand experiences within a learning environment have the advantage to provide insider insights into the design of the environment (Lüdtke et al., 2009). Ongoing assessment of whether and how the mechanism works across individuals and contexts from learners' perspectives should be incorporated into instructional routines. The aim of the integration is to guide improvement-oriented interactions between learners and educators, which leads to iterative cycles of improving learning environment designs.

However, using student evaluations of their learning environment to inform continuous instructional improvement in a UDL-based PL environment is an understudied area. To date, there are no measures that can be used to solicit student perceptions of UDL environmental designs. Thus, future research can focus on how to effectively incorporate evaluations of student learning experiences into the measurement of UDL learning environment designs. Research developing and validating measures to assess student learning experiences with a UDL-based environment is needed.

Conclusion

As education reform efforts continue to call for increasing access to PL for all learners, it is imperative that the design, implementation, and evaluation of PL models be guided by research-based principles or systems. A framework that draws on research investigating effective instructional designs for all learners including students with disabilities will likely have more power in guiding the design of PL experiences for all. This chapter provides such a framework by combining UDL and self-determination and proposing an autonomy-supportive mechanism, aiming to provide guidance on building effective PL models. In particular, building a balance between UDL environmental supports and learner autonomy requires ongoing measurements of the fit, or lack thereof, between the supports and individual learner needs. One potential avenue for future research is to investigate how to effectively involve all learners into the process of assessing UDL environmental supports. Such research holds the great potential for broadening knowledge of how to promoting PL experiences within a UDL environment for all learners.

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Chapter Three: Reviewing Personalized Learning Research Through the Lens of Universal Design for Learning (UDL)

Abstract

Personalized learning (PL), conceptualized as an education innovation that tailors learning to meet diverse student needs, has drawn increased attention from different fields of study. This systematic literature review aimed to provide an empirical integration of PL designs identified from 71 studies (2006-2019) across disciplines through the lens of the Universal Design for Learning (UDL) framework. In line with dynamic systems theory, which provides a lens to view complexity and variability of human learning, UDL guides instructional design for supporting learner variability. Our results indicated that most current studies investigated PL design that focused on only a narrow aspect of learning experience. The analysis of alignment between PL designs within the UDL framework can serve as a starting point for stakeholders to take a more comprehensive approach to designing PL experience. This article ended with discussions about learner variability, role of technology, and data use in PL design.

Keywords: personalized learning, Universal Design for Learning (UDL), dynamic systems theory, learner variability, technology

Currently, a wide range of societal aspects, such as marketing and healthcare, are striving to personalize services to meet individuals' needs (Rose & Ogas, 2018). Within the field of education, personalized learning (PL) or personalization in learning, advocated as a reform effort to transform one-size-fits-all education systems, has gained increased traction with researchers and appeared in education policies around the globe (Peterson, 2016). As an emergent educational phenomenon, PL is defined in varying ways in policies, organization documents, and research reports across contexts. For example, early in 2004, the U.K. Department for Education and Skills (DfES) defined PL as a means of tailoring education to meet individual students' needs, interests, and aptitude so as to fulfill their potential. However, it was reported that the ambiguity and broad sense of the definition led to ineffective practices of the innovation among teachers and researchers in the United Kingdom (Courcier, 2007).

Years later, other countries, such as the United States, are dealing with a similar situation. In order to provide optimal learning experiences for all learners, PL was highlighted in the U.S. federal education law, the Every Student Succeed Acts (ESSA, 2015). Using this as guidance, 33 states addressed PL in their state ESSA plan; however, there was little consensus on the definition or implementation of PL (Zhang, Yang, et al, 2020). In many organization and research reports, PL was broadly defined as instruction and learning activities such as instructional content, materials, learning objectives, and learning pathways tailored to learner preferences, interests, and/or needs (e.g., Basham et al., 2016; Patrick et al., 2013; Pane et al., 2017). The broadness of state and organizational definitions of PL adds a layer of complexity to understand PL implementation. Researchers from different disciplines such as education, learning sciences, and computer science have investigated PL implementation from varied aspects (Zhang, Basham, et al., 2020). However, whether PL has lived up or will be living up to its premise to support all learners in accessing equitable learning experiences remains to be a question (Redding, 2016).

Previous Research Syntheses of PL

Although there is no shared definition of PL or understanding of its implementation, research efforts have emerged that synthesized existing practices and design features of PL. For example, FitzGerald and colleagues (2017) conducted a conceptual analysis of technology-enabled learning (TEL) literature and created a framework for modeling five personalizable dimensions in TEL. These dimensions include what is being personalized, type of learning, personal characteristics of the learner, who/what is doing personalization, how personalization is carried out, and beneficiaries of PL. Using the framework, the researchers analyzed how these dimensions were operationalized in salient PL technologies and techniques including intelligent tutoring systems/adaptive educational hypermedia (AEH), adaptive assessment, science inquiry learning, gaming and informal learning, learning analytics, and personalized books. Additionally, FitzGerald and colleagues (2018) identified potential benefits of personalized TEL to students, educators, and institutions as well as effective mechanisms for personalization in secondary and higher education settings from the literature.

In a previous literature review, we synthesized research investigating PL implementation in PK-12 educational settings and identified two major research trends that emerged from different fields of study (Zhang, Basham, et al., 2020). The first trend focused on examining the effects of PL on student learning in a specific content area. In line with this trend, PL was supported through adaptive technologies or strategies, learner preference-based strategies (e.g., integrating student preference and/or interest into learning activities), ubiquitous/mobile learning systems, and non-adaptive technologies (e.g., learning management system, multimedia tools).

The second research trend focused on investigating characteristics of school-wide PL implementation and contextual factors that impacted PL implementation, mainly through the perspectives of students and/or educators. In this group, PL was implemented through varied school-wide initiatives such as improving learner-teacher interaction, promoting learner autonomy, and provision of choice (see detailed information of these trends in Zhang, Basham, et al., 2020).

These research syntheses show that technology stays in the foreground of the current PL research and practices, with adaptive technologies capturing the most attention. Many adaptive technologies operationalize PL by providing individualized prompts and/or adjusting the difficulty level of learning content based on students' learning behaviors and performance (Basham et al., 2016; Dishon, 2017). This resembles more of a behaviorist model of learning, which heavily depends upon constant reinforcement to shape learning actions (Dishon, 2017). The hint of behaviorist perspective of adaptive technologies can be traced back to the concept of B. F. Skinner's Teaching Machine (1958). Built upon programmed instruction, Skinner's teaching machine was designed to shape learning behaviors by providing prompts, segmenting learning content, requiring mastery, and reinforcing correct responses (Ray, 2004).

Other aspects of PL as advocated by many educational policies and research reports have also emerged, focusing more on student-controlled learning such as increased student voice and choice making (e.g., Miliband, 2006; U.S. Department of Education, 2016), self-directed learning (e.g., Patrick et al., 2013), and interest-driven learning (e.g., Walkington, 2013). Given that designing PL environments that support students' diverse learning needs is complex, we posit that there is no dichotomous question as to whether PL should be driven by technology or human. While technology is critical to operationalizing PL at large scale in modern learning environments (Abbott et al., 2015; Basham et al., 2017), the fundamental question remains as to what designs (with or without technology) make a learning environment personalized for all learners. To support the complex design of PL, it is critical to deepening the understanding of the fundamental concept of "learning" in PL and consider how to support designs for this "learning." Over the next sections, we discuss the complexity of human learning from the perspective of dynamic systems theory (DST) and introduce Universal Design for Learning (UDL) as an instructional framework that guides designs for PL.

Understanding Learning From A Dynamic Systems Perspective

Dynamic systems is a theoretical framework for understanding the process of change and development within a complex system with multiple components interacting at different levels and on different timescales (Connell, Dimercurio, et al., 2017; Smith & Thelen, 2003). The underlying assumption of DST is that the interactions among system components are dynamic, nonlinear, and interdependent, which produce emergent outcomes (Hilpert & Marchand, 2018). Research on DST provided insights into how humans develop and learn differently (see Bidell & Fischer, 1996; van Geert, 1991). Contrary to traditional stage-based accounts of psychological structure and skill construction, DST recognizes complex mechanisms that underpin variability and change in learning (Hilpert & Marchand, 2018). According to the dynamic perspective, variability occurs through interactions between a person and their direct environment (Fischer & Bidell, 2006).

Within a dynamic system, learning occurs when affection, cognition, emotion, and social influence participate in one another's functioning in a specific context and culture (Immordino-Yang & Damasio, 2007). The inter-participating process involves self-regulation in individual activities and mutual regulation with others in social interactions, demonstrating between- and within-individual variations in a dynamic growth (see Fischer & Bidell, 2006; van Dijk & van Geert, 2015). Yet, the variations are norms, relatively patterned, and responsive to contextual influences and supports (Miller et al., 2002).

Drawing upon DST, Cantor et al. (2018) synthesized salient research on development and learning from diverse scientific disciplines. Based on the results, the researchers proposed a holistic, dynamic, and integrated framework for understanding multiple neural, relational, and contextual processes that converge to explain learners as active agents in their own learning with unique developmental processes and learning performance. The integrated understanding indicates that *individual internal attributes* (e.g., prior knowledge and experience, foundational skills such as self-regulation, executive function, and growth mindsets, as well as competencies such as motivation and metacognition) should be acknowledged and supported by *rigorous instructional and curricular designs* that are nested within *positive interpersonal and environmental conditions for learning*. Recognizing human learning as a holistic, dynamic, and complex process provides a rationale for supporting personalization in individual learning experiences. Individual variations should be considered as multiple pathways; thus, students' learning experiences should be designed based on and tailored to these pathways (Cantor et al., 2018; Fischer & Bidell, 2006; Osher et al., 2018).

Instructional Design Framework: Universal Design for Learning (UDL)

Complex learning processes require education to be a complex design profession (Schön, 1979). An instructional design process should start with acknowledging dynamics and variability in human development and learning. The framework of UDL has emerged as an instructional design framework that highlights the centrality of learner variability and promotes flexibility and equity in learning environments (Rose & Meyer, 2002). The development of UDL drew upon decades of interdisciplinary research from learning sciences, neuroscience, cognitive psychology, pedagogy, and educational technology on how the brain processes information and learning occurs (CAST, 2018). The framework provides comprehensive insight into learner variability in three learning-related brain networks (i.e., affective, recognition, and strategic networks) that explain the “why”, “what”, and “how” of learning (Meyer et al., 2014).

The premise of UDL is to proactively design learning environments to support between-learner variability as well as iteratively identify and reduce learning barriers that emerge when the learner interacts with their environment. The framework consists of three principles, which guide environmental designs that offer options for how learners engage in learning, access and internalize instructional content, and demonstrate knowledge. Built within the three principles are nine guidelines and 31 checkpoints that provide design considerations for tailoring learning goals, assessments, instructional methods, and materials to diverse learning needs (Meyer et al., 2014). More detailed descriptions of UDL guidelines and checkpoints will be provided later in the following sections.

Taken together, the dynamic systems perspective of human learning suggests PL design and implementation are complex, involving considerations for supporting dynamic learner-environment interactions. The UDL framework, with an emphasis on designing learning environments and experiences that support learner variability, has potential to provide foundational considerations for PL design and implementation. Framing an understanding of PL through the lenses of DST and the UDL framework is critical to advancing PL design and implementation.

Purpose of the Study

Our previous literature review provided a comprehensive understanding of the research foci and characteristics of current PL implementation studies (Zhang, Basham, et al., 2020). To expand the previous study, the present study analyzed if or how empirical PL designs and implementation practices emerging from the literature aligned to the UDL framework. The purpose of the synthesis is twofold. First, the synthesis aimed to use the UDL framework to integrate PL designs and practices found in the current literature, thereby identifying PL design variables within a unifying framework. Second, this synthesis explored emergent factors that impacted PL implementation and how learner variability was addressed in current PL studies. The following research questions guided this review:

1. To what extent do the current PL designs or practices align to the UDL framework?
2. What are the emergent contextual factors that would impact PL implementation?
3. To what extent are students with diverse needs included in PL implementation studies?

Method

Literature Screening and Inclusion Criteria

Our previous literature review included 71 articles investigating PL implementation that were published between 2006 and 2019 using the method of critical interpretive synthesis (CIS; Dixon-Woods et al., 2006). The present study used the same literature base as the previous study. To summarize, empirical studies investigating PL implementation in PK-12 educational settings were identified through a comprehensive literature search of four online databases including ERIC, OmniFile Full Text Select, Academic Search Complete, and Web of Science. The search terms included: "personali*e(d) learning", "personali*e(d) e-learning", "personali*e(d) distance learning", "personali*e(d) online learning", "personali*e(d) education", "personali*e(d) online education", "personali*e(d) distance education", "personali*e(d) instruction." We also used three combinations of keywords (i.e., personali*ation and learning, personali*ation and education, personali*ation and instruction) as search terms. Studies were included if they employed an empirical design, focused on PL implementation in PK-12 educational settings, and were written in English and published in peer-reviewed journals. More detailed information on screening and identifying relevant literature as well as inclusion and exclusion criteria can be found in Zhang, Basham, et al. (2020).

Coding System

In the previous literature review, we categorized the identified studies into Group A across four clusters (A1 through A4) and Groups B across four clusters (B1 through B4) based on an iterative and comparative analysis of research foci across studies (Zhang, Basham, et al., 2020). Specifically, Group A studies examined how technologies such as adaptive learning systems or intelligent tutoring systems (A1), learner preference-based personalization strategies (A2), mobile learning systems (A3), or non-adaptive digital tools (A4) supported PL design and implementation. Group B1 studies explored design characteristics of PL environment, and Group B2 investigated teacher-mediated strategies to implementing PL as school-wide initiatives. Rather than focusing on specific PL technologies or strategies, Group B3 and B4 studies explored contextual factors that might impact PL implementation and teacher and/or student perceptions of PL policies or concepts, respectively. This categorization of research trends guided the development of a coding system to extract information pertinent to the three primary research questions in this study (see a detailed summary of each reviewed study in Supplemental Table). First, we coded PL designs and/or implementation features identified from studies in Group A, Group B1, and Group B2 (see Table 1). These studies investigated specific PL strategies and/or characteristics of PL environments (Zhang, Basham, et al., 2020). To evaluate the alignment between the identified PL designs to UDL, we used the UDL Guidelines 2.0., which is an articulation of UDL design guidance released by CAST (2018; see Figure 1). We coded whether identified PL designs aligned to research-based strategies, suggestions, or examples for designing or implementing each UDL checkpoint offered on the CAST website (see examples at http://udlguidelines.cast.org/engagement/recruiting-interest/choice-autonomy).

Group B3 and B4 studies were coded to address the second research question. Group B3 studies focused on exploring factors that impacted the implementation of school-wide PL initiatives. Group B4 studies investigated participant perspectives (e.g., students, educators) of PL policies, reforms, and/or concepts. Accordingly, we followed the open coding procedure to identify the primary factors that might influence the PL implementation emerging from these studies, allowing individual codes to cluster around related themes (Brown et al., 2002).

Regarding learner variability, we coded whether descriptions of participant characteristics were provided in each study. Three categories were applied to code participants' variability within a study, including (a) no explicit descriptions, if the study reported no participants' learning or demographic characteristics; (b) brief description, if the study reported at least one participants' learning or demographic characteristics such as gender, ethnicity, and socioeconomic status; and (c) detailed description, if the study provided multiple aspects of the participants' learning or demographic characteristics. Whether the studies recruited students with disabilities, struggling or low-achieving students, or special education teachers as research participants was coded as well.

Interrater Reliability

Four steps were taken to establish interrater reliability for coding the UDL alignment. Before independent coding, the first author and another co-author familiarized themselves with the UDL Guidelines 2.0 and design considerations for each UDL checkpoint provided by CAST. Additionally, the two researchers analyzed varying PL definitions from different research reports and policy documents (e.g., Chen, 2008; Patrick et al., 2013; U.S. Department of Education, 2016 Walkington & Bernacki, 2015; Zhang, Basham, et al., 2020). This definition analysis guided the researchers in aligning potential PL designs and practices as reflected in the widely adopted PL definitions to the UDL framework.

The two researchers proceeded to independently code one article selected from the pool of Group A, Group B1, and Group B2 studies. Interrater reliability for the training coding was estimated with Cohen's Kappa (κ). A Kappa (κ) = .613 with 95% of confidence interval (CI) ranging from 0.416 to 0.810 was achieved, indicating substantial agreement among the coders (Landis & Koch, 1977). Afterward, the first author coded all other articles from the pool, and the other author independently coded 20% (n = 11) of the articles, which were randomly selected from the pool. As suggested by Landis & Koch (1977), the interrater reliability on the initial coding before consensus was excellent, $\kappa = 0.89$, 95% CI [0.86, 0.93]. In addition, the interrater reliability on the coding of learner variability reached a substantial agreement, $\kappa = 0.70$, 95% CI [0.479, 0.921]. Disagreements on interpretations of coding were resolved through discussion.

Results

Alignment of PL Practices with the UDL Framework (RQ 1)

In this section, we presented the alignment of specific PL designs and implementation practices investigated in Group A, Group B1, and Group B2 studies to the UDL principles, guidelines (hereafter G), and checkpoints (hereafter, CP; see Table 2). We briefly explained each UDL principle, followed by a summary of how identified PL practices or strategies aligned to associated guidelines and checkpoints under each principle.

Provide Multiple Means of Representation

According to UDL, providing options for perceiving information (G1), understanding language and symbols (G2), and comprehending learning content (G3) would make learning more accessible for learners with diverse abilities (CAST, 2018). These UDL design suggestions have potential to inform PL environments. In one study, PL was viewed as access to flexible learning materials for students with varying preferences (Ertem, 2013). Specifically, Ertem (2013) found that increased student autonomy over the format of online reading text (e.g., background color, font style) positively impacted reading comprehension performance. This design increased flexibility of how information was displayed (aligning to UDL CP1.1). Arroyo et al. (2014) reported increased math fluency when students used a mathematical fact retrieval (MFR) software system with a text-to-speech function embedded in an intelligent tutoring system [ITS] called Wayang. The MFR software allowed users to speak math answer aloud and hear the correct answer spoken back to them. This feature was designed to stimulate both auditory/verbal and visual/spatial component of math fluency for learners, aligning to the UDL design consideration for offering alternatives for visual information (CP1.3).

Researchers of the UDL framework suggest that effective instructional strategies should ensure clarity and comprehensibility in language and symbols illustrated through multiple media across all learners (G2; CAST, 2018). However, this UDL guideline has found little trace in current PL practices or technologies. Only three studies reported that learners were given options for comprehending learning materials in multiple media formats (CP2.5). Arroyo et al. (2014) reported that ITSs allowed students to access information through multiple modalities such as animations and instruction videos. The other two studies reported that as a characteristic of PL environments, learners were supported in making choices among multiple media resources for gaining information (Basham et al., 2016; DeMink-Carthew & Netcoh, 2019).

By comparison, current PL designs demonstrate potential to support learners in processing information (G3) such as activating background knowledge (CP3.1), identifying important features in information (CP3.2), applying meta-cognition to categorize and prioritize information (CP3.3), and transferring knowledge (CP 3.4). For example, two studies examined how mobile learning systems were designed to help activate learners' relevant prior knowledge (Song et al., 2012) or automatically link to pre-requisite information (CP3.1; Hwang, Tsai, et al., 2012). Aligned to CP3.2, some adaptive learning systems were able to provide functions such as underlining, drawing on figures (Arroyo et al., 2014), and highlighting text with varying colors (Siddique et al., 2019) that could help direct students' attention to important parts of learning concepts.

A large number of studies on adaptive learning technologies, robotics, or computer games examined PL designs that support learner information processing (CP3.3) through built-in adaptive cognitive tools or functions. These systems were reported effective in providing customized scaffolds, hints, guidance, and/or assessment for individual learners (e.g., Alcoholado et al., 2011; Chu et al., 2010; Cornelisz & van Klaveren, 2018). For example, many systems progressively release information to allow students to progress based on demonstrated mastery of academic content (e.g., Baxter et al., 2017; Cornelisz & van Klaveren, 2018), provide sequentially ordered chunks of information (e.g., Siddique et al., 2017), or use adaptive annotation techniques or animated agents to prompt learners to focus on the concepts as needed (Katsionis & Virvou, 2008; Wang, 2014). Similarly, several mobile learning systems operating on adaptive mechanisms were designed to assist learners with individual guidance or deliver customized materials based on where they were located and/or how they performed (e.g., Chen & Li, 2010; Hsu et al., 2013). Looi et al. (2009) examined how a mobile learning system personalized student learning by providing multiple entry points and learning paths during a field trip. Only one study reported modeling the “think aloud” technique and concept maps as a teacher-mediated practice in a PL environment (Abawi, 2015).

In addition, the ITS examined in Arroyo et al. (2014) provided a “help fading” technique that could simultaneously assign learners a new problem of similar difficulty after they learned one math problem. This function was designed to encourage learners to transfer knowledge to subsequent questions (CP 3.4). Taken together, these PL design features show alignment between multiple fields including computer science, education, and learning sciences.

Provide Multiple Means of Action and Expression

Learners differ in how they navigate a learning environment, demonstrate what they learn, and apply executive function skills (CAST, 2018). Aligned to UDL, effective learning environments should provide alternative means for navigating instructional materials or interacting with educational technologies (CP4.1) and optimizing access to digital tools or assistive technologies, especially for students with disabilities (CP4.2). Currently, only one PL study reported that assistive technologies were used as a personalized support mechanism in an inclusive learning environment (Abawi, 2015).

UDL guides instructional designs that allow learners to express knowledge in multiple modalities (CP5.1) with multiple tools (CP5.2) and scaffolds or graduated level of support as they practice and develop independency (CP5.3; CAST, 2018). Aligning to these design considerations, three studies investigated how PL environments (Basham et al., 2016) or mobile learning systems (Song et al., 2012; Looi et al., 2009) supported learner autonomy in demonstrating understanding and mastery. For instance, mobile learning systems designed by Song et al. (2012) and Looi (2009) provided flexible and accessible toolkits for learners to create versatile and multi-modal (pictures, tests, or both) project products. Moreover, Arroyo et al. (2014) examined a “help fading” function which gradually reduces support in math learning until the students demonstrate mastery (aligning to CP5.3).

Compared to the other two UDL guidelines for action and expression, more PL studies examined technologies and practices that helped develop learners’ executive function skills (G6; Meyer et al., 2014). These practices include assisting students with appropriate goal setting (CP6.1), planning and strategy development (CP6.2), managing information and resources (CP6.3), and monitoring progress (CP6.4). For instance, Song et al. (2012) analyzed how a goal-based experiential learning model operating on a mobile system assisted students in understanding and developing personalized goals. Five studies explored how goal-setting strategies, mainly mediated by humans (i.e., students, teachers), were implemented in PL environments (e.g., Basham et al., 2016; DeMink-Carthew & Netcoh, 2019). For example, DeMink-Carthew et al. (2017) identified student independent design, interest-driven student-teacher codesign, interest- and skill-driven student-teacher codesign, skill-driven student-teacher codesign, and student selection of prescribed goals as five dominantly-utilized strategies for goal setting in a PL environment.

Only two studies discussed how planning tools or strategies were used to support learners in taking action toward goals (CP6.2) or managing resources (CP6.3). Specifically, Abawi (2015) reported that in PL environments, students were supported in planning to achieve goals without providing explicit strategies. DeMink-Carthew and Netcoh (2019) found that students co-planned learning projects with teachers as well as received feedback on their planning tools, resources, and instruction on note-taking skills in a PL environment.

Supporting students in enhancing capacity for monitoring progress such as self-evaluation and self-assessment skills (CP6.4) has emerged as a PL strategy either mediated by teachers (e.g., Basham et al., 2016; DeMink-Carthew & Netcoh, 2019) or facilitated by technologies (e.g., Chen, 2009b; Song et al., 2012). For example, adaptive learning or assessment systems were effective in providing students timely feedback and individual reports on learning progress for self-assessment (e.g., Chen, 2009b; You et al., 2019). Basham et al. (2016) and DeMink-Carthew & Netcoh (2019) both found that in PL environments, students were frequently given opportunities to review progress data and self-assess learning goals in learner-teacher conferences.

Provide Multiple Means of Engagement

One key tenet of UDL is to enhance student engagement in a learning environment designed to increase interest (G7), sustain effort (G8), and develop self-regulation skills for all learners (G9; CAST, 2018). Current PL studies reported varied interest-driven strategies for optimizing individual choice and autonomy (CP7.1). These strategies include, but not limited to, involving students in making decisions on what to investigate and/or how to demonstrate understanding (e.g., Basham et al., 2016; Looi et al., 2009), allowing students to choose learning tasks based on interest (e.g., Choi & Ma, 2015; Clinton & Walkington, 2019), and increasing student autonomy through interest-driven goal setting and choice making (DeMink-Carthew et al., 2017; Netcoh, 2017).

Seven studies reported that ubiquitous/mobile learning systems provided authentic learning experience (CP7.2) through field trips or outdoor activities (e.g., Chu et al., 2010; Chen

& Li, 2010). With wireless positioning techniques, these systems could deliver context-aware learning materials for students, which enhanced interaction of students with the learning context and thus evoked interest and curiosity (e.g., Hsu et al., 2013; Song et al., 2012). Mobile phones were also used by students to capture their daily life as a way of increasing authenticity in learning (Hartnell-Young & Vetere, 2008). Moreover, twelve studies examined the effectiveness of context personalization strategy in which student interests or preferences (CP7.2) were integrated into math learning materials (e.g., Ku et al., 2007; Walkington, 2013). Multiple studies investigated leveraging digital storytelling tools (Kaminskienė & Khetsuriani, 2019), customizing reading materials (e.g., Kim et al., 2019; Kucirkova et al., 2014), facilitating goal setting to connect to learner preferences or interests (DeMink-Carthew et al., 2017) as personalization strategies. Additionally, two studies described how culturally responsive approaches (CP7.2) supported a small sample of students from culturally diverse groups in literacy classrooms (Mottram & Hall, 2009; Worthy et al., 2012). To minimize threats in learning environments (CP7.3), one study found that students had access to safe and quiet places within a reduced-stress learning system as one type of PL supports in an inclusive school (Abawi, 2015)

Table 2 illustrates a great extent of alignment of PL designs to UDL G8. This guideline offers design considerations on supporting students in sustaining efforts through consistent reminders of goals (CP8.1), proper challenges (CP8.2), collaborative learning opportunities (CP8.3), and mastery-oriented feedback (CP8.4). For example, Chen (2009b) developed an adaptive learning system, which could display target learning time and achievement indexes as a reminder and support for learners to self-monitor goal setting (CP8.1). Many studies examined various adaptive technologies (e.g., ALS, ITS, virtual reality system, robotics) that were designed to customize learning content, sequencing, or path to adjust the degree of difficulty of learning materials or return learning tasks that require additional practices for individual students as one aspect of PL (CP8.2; e.g., Chen, 2008; Leyzberg et al., 2018; Su et al., 2006; You et al., 2019). Four studies explored how teachers provided varied levels and types of demands and resources to meet diverse learning needs, such as grouping students based on their needs, strengths, and/or weaknesses (e.g., Connor et al., 2018; Kim et al., 2019).

Similarly, many studies investigated how human-mediated and technology-driven practices were implemented to foster learner collaboration and interaction (CP8.3) within PL contexts (e.g., Hsu et al., 2013; Katsionis & Virvou, 2008). Multiple studies examined practices primarily mediated by teachers to utilize student performance data, with or without technological support, to group students for completing appropriate learning activities (Connor et al., 2018; Hammerschmidt-Snidarich et al., 2019), collaborating to demonstrate learning products (DeMink-Carthew & Netcoh, 2019), or engaging in peer interactions and contributing to classroom communities (Worthy et al., 2012). Two studies reported increased interactivity (e.g., sharing artifacts and reading annotations) among students through a mobile learning system (Looi et al., 2009; Hsu et al., 2013). Supported by adaptive technologies, virtual learning companions were reported effective in delivering hints to promote student effort, learning outcomes, and sense of collaboration (Arroyo et al., 2014; Baxter et al., 2017; Chen, 2009b; Katsionis & Virvou, 2008). Additionally, these adaptive technologies were found to be useful in providing real-time feedback or affective messages emphasizing efforts or conveying informative reasons behind mistakes (G8; e.g., Chen, 2009b; Siddique et al., 2019).

Lastly, UDL-aligned strategies support learners in developing self-regulation skills (G9) with foci on promoting expectations (CP9.1), facilitating personal coping skills (CP9.2), and developing self-assessment and reflection (CP9.3; CAST, 2018). Three studies investigated student learning and motivation within PL systems or environments designed to promote expectations and beliefs (CP9.1; Abawi, 2015; Basham et al., 2016; Chen, 2009b). For example, Chen (2009b) developed a PL system based on Zimmerman's self-regulated learning model. The system could automatically generate individual self-regulation radar plot showing learning time, effort level, reading rate, and concentrated study time to help learners understand the difference between current and target self-regulation indexes, thereby encouraging self-learning motivation. Other digital learning/assessment systems or human-mediated strategies were examined for their effectiveness in supporting student self-evaluation, assessments, or reflection (CP9.3; e.g., Song et al., 2012; You et al., 2019). It is important to note that instructional design suggestions to address UDL CP6.4 and CP9.3 provided by the CAST website overlap to some extent. Thus, we coded PL practices for promoting student self-monitoring, self-assessment, or self-reflection as aligned to both CP6.4 and CP9.3.

The Extent of UDL Alignment

As demonstrated in Table 1, current PL strategies and/or design features were widely mapped onto the UDL framework. Of the 31 UDL checkpoints, nine checkpoints (i.e., 1.2, 1.3, 2.1, 2.2, 2.3, 2.4, 4.1, 5.2, 9.2) were not found to be aligned to any PL design from the articles reviewed in this study. Additionally, Table 1 shows that PL strategies identified from the current literature follow a certain pattern of alignment to UDL. For instance, adaptive technologies (in Group A1 studies), which provided individual feedback, graduated scaffolds, guidance, and/or customizable learning paths, could support information processing (CP3.3) as well as automatically vary demands and challenges for individual learners (CP8.2). Learner preference-based strategies for personalization (in Group A2 studies) focused on recruiting individual interest in learning materials and activities, which optimized relevance and authenticity of learning (CP7.2). Mobile learning systems (in Group A3 studies) supported authentic learning via field trips and allowed for enhanced student autonomy over where and what to learn with individual guidance (CP3.3 and CP7.2).

Several studies reported a relatively more comprehensive application of technology to support students' PL experiences through the lens of UDL. For example, the ITS investigated in Arroyo et al. (2014) and the mobile learning system in Song et al. (2012) were aligned with UDL in varied aspects. These aspects include, but not limited to, customizing learning content, allowing for multiple modalities of demonstrating learning, supporting authentic or affective learning experience, and promoting self-regulation. Additionally, three other studies exploring salient features of PL environments or school-wide PL initiatives showed a relatively wide extent of UDL alignment (Abawi, 2015; Basham et al., 2016; DeMink-Carthew et al., 2017). For example, Basham et al. (2016) described a variety of design characteristics of a district-wide PL environment, seven of which aligned to UDL design considerations with an emphasis on providing multiple means of expression and engagement. DeMink-Carthew and Netcoh (2019) explored students' experiences within a PL environment; eight instructional designs emerged that aligned to UDL, especially to G6 that focuses on promoting student executive function skills through increased autonomy in choice making. Moreover, PL strategies investigated in two studies showed no alignment to UDL (McClure et al., 2010; Iver, 2011). These studies explored providing or enhancing teacher-student relationships as one type of PL strategy to promote individual students' sense of belonging.

Contextual Factors Regarding PL Implementation (RQ2)

Researchers investigated a wide range of emergent contextual factors (Group B3 and B4 studies) that would impact the adoption and implementation of PL. Although limited in the number of studies, several main themes, such as technology, professional development, and assessment, emerged as both driving forces for and constraining factors of implementing PL.

Technology

Seven studies in Group B3 stressed the importance as well as challenges of using technology to diffuse and implement PL (i.e., Bingham & Dimandja, 2017; Bingham et al., 2016; Ignatova et al., 2015; Karmeshu et al., 2012; Olofson et al., 2018; Robinson & Sebba, 2010; Schmid & Petko, 2019). Increasing students' access to and ownership of digital tools and diverse learning resources could facilitate their PL experiences (Ignatova et al., 2015; Robinson & Sebba, 2010). Empowered by technology, students were afforded more opportunities to engage in student-led learning activities (Robinson & Sebba, 2010), gained more autonomy over learning processes (Ignatova et al., 2015), and increased digital skills (Schmid & Petko, 2019). In addition, teachers benefited from using technology to deliver whole-class instruction (Robinson & Sebba, 2010) and reduce their workload (Karmeshu et al., 2012). Regardless of the perceived power of technology, Bingham et al. (2016) found that a misalignment between schools' technology infrastructure and teachers' technology needs existed as a major obstacle to implementing PL across 28 case study schools.

Professional Development

Three studies reported the importance of providing teachers with sufficient, targeted training and professional development given the high expectations for teachers' technology use in a PL environment (i.e., Bingham et al., 2016; Karmeshu et al., 2012; Robinson & Sebba, 2010). Drawing upon large-scale teacher perception data, Karmeshu et al. (2012) identified in-service teacher training for pedagogical methods and instructional technologies as one of the dominant factors that would influence teachers' decision to adopt PL. Similarly, Robinson and

Sebba (2010) reported that school supports for professional development and technical supports afforded teachers opportunities to personalize learning, thus serving as a driving force for implementation. However, Bingham et al. (2016) found that most teachers from their case study schools experienced insufficient training and professional development, resulting in a gap between their capacity and high requirements for successfully implementing PL.

Ongoing Assessment

In addition to technology accessibility and professional development that could serve as both driving forces and obstacles, how to assess student performance also emerged as a difficult issue associated with PL implementation (e.g., Bingham et al., 2016; Ignatova et al., 2015). For instance, as reported in Ignatova et al. (2015), personalization in student learning processes would be potentially afforded by flexible student evaluation methods (e.g., allowing for student self-assessment and self-reflection) associated with adaptive curriculum and flexible learning space. Ongoing assessment of students' progress toward goals as well as effective utilization of student mastery and achievement data serve as a critical aspect of PL. However, Bingham and Dimandja (2017) reported that more experienced teachers in their case study schools were more resistant to the idea of utilizing assessment-generated data to inform instructional adjustment. Furthermore, Bingham and colleagues (2016) pointed out that how student success was measured in most PL schools (e.g., mastery-based grading) conflicted with the traditional expectations for standardized testing and college admission requirements.

Factors Emerging from Participant Perceptions

Three studies in Group B3 reported on the validation of a student self-report instrument called Personalized Learning Environment Questionnaire (PLEQ; Waldrip et al., 2014; Waldrip et al., 2016) and a teacher self-report instrument (Olofson et al., 2018), both of which were reported suitable for measuring factors supporting PL practices. The PLEQ consists of four main constructs, namely, self-directed learning readiness, learning environment, student engagement, and individualized assessment (Waldrip et al., 2014). In a follow-up study, Waldrip and colleagues (2016) tested a PL model under the Australian context using the instrument. They found that students' perceptions of self-directed learning readiness, cognitive engagement, and alignment of assessment tasks with planned learning and real-life situations were all positively associated with academic efficacy. Olofson et al. (2018) also identified personalized assessment, out-of-school learning, whole group learning in a personalized setting, technology implementation, and cultural responsiveness as the main constructs of the instrument for measuring teaching practices of middle-grade teachers. Additionally, Kallio (2018) identified flexibly designed physical learning spaces as a critical factor for implementing PL.

Four studies in Group B4 primarily explored teachers' and/or students' perceptions of PL in terms of how its concepts, policies, and/or practices impacted implementation (Beach & Dovemark, 2009; Courcier, 2007; Hallman, 2018; Rogers & Gunter, 2012). Courcier (2007) indicated that similarity among concepts of personalized, individualized, and differentiated learning caused confusion among teachers in North East England. The confusion, thus, hindered them from applying identified approaches to carry out effective PL practices in the classroom. Similarly, Hallman (2018) reported a practitioner's mixed feelings toward a PL implementation through 1:1 technology initiative.

In the other two studies that mainly analyzed how PL policies were operationalized in schools, learner autonomy was at the center of discussion. Beach and Dovemark (2009) found that from the teacher and student perspectives, granting students more freedom to make choices and work at their own pace resulted in a new form of private consumerism in education because educational materials were mobilized toward students from families with more financial and cultural capital in a Swedish school. Similarly, Rogers and Gunter (2012) reported negative student perceptions of PL policies in England as their voices were subsumed when schools compiled learning goals using student performance data, only to ensure good examination results for all students rather than connect to potential or interests of individuals.

Overview of Learner Variability (RQ3)

Table 3 shows that many studies (*n* = 21; 30%) did not provide explicit information on learner variability. Forty-one studies (57%) briefly described one or more student participants' demographic characteristics, such as gender, socioeconomic status, ethnicity, and learning difference. Seven studies did not include student data (e.g., Courcier, 2007; Karmeshu et al., 2012). In total, only ten included students with disabilities (e.g., Bhattacharjee et al., 2018; Robinson & Sebba, 2010; Clinton & Walkington, 2019), and three studies included special education teachers as research participants (Abawi, 2015; Courcier, 2007). One paper specifically reported that no students with special needs participated in the study (Høgheim & Reber, 2015). Five studies reported the academic performance of participants identified as struggling or low-achieving students (e.g., Arroyo et al., 2014; Choi & Ma, 2015). Only two studies provided a detailed description of student learning variability, all being small-scale qualitative research that investigated specific students' learning activities (Mottram & Hall, 2009; Worthy et al., 2012).

Discussion

This synthesis provided empirical weight to an understanding of designing PL for all students. From the complex dynamic systems perspective, learning is a complex phenomenon, taking place in the dynamic interactions between individual learners and their learning environment (Cantor et al., 2018; Fischer & Bidell, 2006). Guided by this perspective, this synthesis analyzed how current empirical PL practices aligned to UDL design suggestions and explored emergent factors that would impact PL implementation. Our results indicated that most current studies investigated PL design and/or implementation by focusing on one or several personalization features. These PL features were designed to support only a narrow aspect of learning experience. More complex PL designs should be investigated based on an understanding of the dynamic nature of learning and human variability.

The dynamic systems perspective on learning helps conceptualize PL as a complex, emergent, nonlinear process characterized by between- and within-learner variability, supported by flexible instructional designs, and mediated by environmental conditions for instruction and learning. Most current PL studies investigated segmented aspects such as student attributes (e.g., interest, motivation, self-regulation; Chen, 2009b; Clinton & Walkington, 2019), instructional practices (e.g., facilitating goal setting; Netcoh, 2017), or environmental factors (e.g., enhanced teacher-student relationship, cultural responsiveness; McClure et al., 2010; Worthy et al., 2012) that could contribute to designing PL experiences for students. Rarely did studies investigate how PL was operationalized in a system integrated with design components supporting neural, relational, and contextual processes for individual learners. This finding is not surprising given PL is still in its infancy, and little is known about what an integrated system that supports complex, dynamic, and unique learning processes for all learners should look like.

In addition, the alignment analysis revealed a vast amount of variations and complexity in PL design, which arose from the broad definitions of PL and interdisciplinary approaches to its implementation. For example, a large number of PL studies explored varying technologies and strategies that aligned to guidance offered by UDL checkpoint 8.3 on designing effective learning environments that vary demands of learning tasks and resources to optimize challenge. These technologies include ALS, ITS, virtual reality, and robotic systems that could adapt learning content, path, sequence, and/or materials based on student data such as prior knowledge and level of ability (e.g., Cornelisz & van Klaveren, 2018; Siddique et al., 2019). Most of these technologies were found to be effective in adapting the level of challenge of learning tasks and guiding students' cognitive learning within their zone of proximal development (ZPD; Vygotsky, 1929). Teacher-mediated strategies such as providing flexible learning groups, structures, or resources in the classroom were also explored as a means of varying demands of tasks based on learner needs (e.g., Connor et al., 2018; Edmunds & Hartnett, 2014). When students interact with adaptive technologies, a vast amount of data can be utilized to build user profiles, automate assessments, and create appropriately adjusted learning content. Teacher-mediated instructional designs such as flexible grouping are complex in itself. However, to maximize the benefit of flexible grouping, teachers will need a sound understanding and ability to analyze the massive amount of data that these adaptive technologies produced. Ultimately, students will benefit from using technology that supports neural learning process as well as interacting with teachers and peers within flexible groups that facilities relational learning process.

In addition, PL is not merely about adapting learning content or materials; instead, adaptation technique only serves as one design component within a complex PL system. A detailed analysis of how varying PL designs could be interwoven within each UDL checkpoint is beyond the scope of this review. However, it is hoped that our analysis of the alignment between empirical PL designs and the UDL framework can serve as a starting point for researchers, instructional designers, educational technology developers, practitioners, and other stakeholders to take a more comprehensive approach to designing PL experiences for all learners. In particular, the complexity in PL design indicates that a mixture of machine-based and human-driven factors is most likely needed for operationalizing PL as a dynamic supporting system for learners. When various instructional designs and driving factors converge to support PL design, future research should also carefully address issues that emerged from the literature. These issues include concern of learner variability, the paradoxical role of technology, and a need for fair use of student data. In what follows, we discussed these issues and provided implications for future research and practice.

Concern of Learner Variability in PL Research

Currently, few studies on PL had taken into consideration the variability in individual learning needs. Only a few studies noted learners with diverse learning needs, including those with identified learning differences (e.g., disabilities) as participants. This issue could emerge due to the lack of demographic information provided or could actually be the lack of recognized diversity of the participants. The latter situation obviously embodied itself in the above-reviewed study that reduced student variability by explicitly stating that students with special needs were not included in the investigation (see Høgheim & Reber, 2015).

Given that the central premise of PL is focused on supporting the needs of learners, ideally all learners, supporting recognized learner variability in research is necessary for advancing understanding across the field. Minimally, this requires the recruitment of more diverse participants as well as explicitly identifying participant variability. Engaging all learners, rather than a narrow group, increases the complexity of designing and implementing PL. This complexity derives from the enormous flexibility in learning environments needed for addressing student variability and individual learning needs. As discussed above, a majority of current research efforts, either on designing PL tools or investigating contextual factors that impacted PL implementation, did not comprehensively address such enormous flexibility.

Paradox of Technology in PL

Currently, many PL interventions and projects were closely tied to and supported by technology, such as ALS, mobile devices, and computer games (e.g., Martín-SanJosé et al., 2014; Walkington, 2013). These technologies possess functions, such as collecting in situ student data, delivering immediate and adaptive feedback, and/or providing means to access information ubiquitously (e.g., Song et al., 2012). Several advanced learning platforms such as the virtual reality system in Bhattacharjee et al. (2017) and the IST in Arroyo et al. (2014) were developed building upon an interdisciplinary understanding of different aspects of learning. Both systems were reported effective in delivering PL experiences tailored to the cognitive, affective, and metacognitive needs of individual learners. For example, the PL mechanism supporting the virtual reality system is to simulate the learning environment to adapt to the participants' needs by providing various sensory information.

Concerns also emerged regarding the role and extent to which technologies should play in implementing PL. For instance, whereas many adaptive technologies are capable of adapting learning materials or pathways automatically, this adaption mechanism contradicts a crucial construct of PL—learner self-regulation and autonomy. As Zhao (2018) argues, PL, especially those supported by advanced technologies, restricts student autonomy to choices that are often influenced heavily by preconceived theories or big data that informed design of a PL platform. Another potential underlying problem is that the adaptive mechanism of some adaptive technologies are built on learning style. This mechanism places students into different groups to receive learning materials aligned to one specific style. In this review, for instance, several learning systems measured participants' learning preferences using learning style inventories and then adapted learning paths, materials, or learning modes based on students' diagnosed style (e.g., Hwang, Sung, et al., 2012; Kurilovas et al., 2015; Su et al., 2006; Tseng et al., 2008). However, as currently understood, the use of learning styles has little scientific merit (Kirschner, 2017).

Need for Fair Data Use in PL

Modeling learner variability to provide personalized supports for individual learners requires collecting and utilizing individual student data to inform day-to-day instructional decision making (Rose & Ogas, 2018). Many above-reviewed studies did emphasize using assessment data as a key operational element of PL, regardless of varying concepts of the innovation and tools for data collection (e.g., Chen, 2009a). It is important to note that data-driven practices to personalize learning should depend on the fair use of data for continuous improvement and transparency in data collection procedures. However, neither of these has been addressed sufficiently in current research efforts.

Educational data are heterogenous (multiple data sources), hierarchical (multiple levels), and dynamic in nature (changing over time; U.S. Department of Education, 2012). This implies that using single-dimensional datasets such as summative assessment scores to model PL would reduce the complexity of learning processes, thereby producing bias against students' learning goals, progressions, and needs. The current review revealed that technology-based data systems have not yet served as a powerful tool to facilitate instructional decision making. For instance, most of those systems, especially ALS, simply advanced simplistic linear models of student learning (e.g., Kurilovas et al., 2015). Additionally, technological infrastructures of many schools that implemented PL were not yet ready for establishing a robust, integrated data system to generate, deliver, and manage accurate student data (Bingham et al., 2016).

Implications for Future Research and Practice

To our knowledge, the present study was the first attempt in the field to investigate complex PL designs within UDL as a unifying framework. As its name suggests PL should be contextualized to individual learners and support the dynamic learner-environment interaction. Fundamentally, designing PL experiences has potential to disrupt traditionally static learning settings. Researchers across disciplines should work collaboratively to explore how PL technologies, human-driven factors for PL implementation, school-level implementation systems or climate effectively to address varying learning needs of all students. We provided implications for future design and implementation of PL focusing on these aspects in the following section.

Design Centered Around Learners

The framework of UDL provides baseline considerations for designing PL experiences for all learners from the onset and iterative guidance on supporting learner variability emerging from learner-environment interactions. It is important to note that to implement PL based on UDL does not mean to incorporate every guideline or checkpoint into a single educational setting. Design considerations for PL should always start with learner needs. The dynamic development of growth and human learning requires a dynamic support system in which UDL can be utilized in a flexible fashion to respond to specific design needs. As noted before, the results of alignment analysis revealed that varied strategies and/or tools have potential to support implementation of each UDL checkpoint. In addition, flexible designs with considerations for various combinations of UDL checkpoints are determined by contextualized student needs in a specific learning environment. To help disentangle the complexity of providing optimal learning experiences for all, our work of framing PL within the UDL framework provides guidance on unifying PL designs and strategies from a diverse body of literature. We suggest that more interdisciplinary research be needed to investigate PL within a complex system using UDL as a baseline design framework and examine how flexible instructional designs and/or learning technologies can support individual trajectories in learning and growth.

Given that use of technology and data emerged as two interrelated components integral to PL implementation, we also recommend researchers in the field look at the role of technology and data in PL implementation from a user-centered design perspective. Human-centered technology design and development requires working through many of the various issues identified in this article. Minimally, it requires the adoption of human-centered design (HCD) or user-centered design models (Baek et al., 2007) that integrate interdisciplinary understandings into the development of new systems to support the variability inherent within learning environments. Accordingly, there is a need for researchers from different disciplines to work collaboratively to support the design of more advanced solutions for real-world learning environments. Meanwhile, there is a need to enhance learner capacity and various teaching practices alongside technology and data systems to sustain ongoing PL (Abbott et al., 2015). For instance, Robinson and Sebba (2010) found that when it comes to the use of technology, the more ownership of digital technologies students have, the more likely learner-driven PL would take place. Future research can focus on investigating how to support students in developing skills such as self-regulation and self-determination needed for engaging in PL experiences, especially in a blended or online learning environment when no immediate educator support is present.

Professional Learning at Teacher Level

Current research has shown that insufficient training and professional development emerged as a challenge for educators to successfully implement PL (Bingham, 2016). The need to design PL for all can be a daunting task. Therefore, educators will need better support in implementing PL. However, previous research has shown that how educators have been educated and trained were not effective in meeting their individual professional learning needs, thereby not effective in supporting them to personalize instruction to meet students' diverse needs (Parsons et al., 2017; Yurtseven Avci et al., 2019). These challenges become more prevalent when educators need to teach in evolving, complex learning environments. To address these challenges, researchers posit that educators benefit from engaging in personalized, self-directed learning and development, which could be transferred into effective instructional practices that yield positive changes in students' PL experiences (Yurtseven Avci et al., 2019; Hunt et al., 2019). Therefore, another direction for future research is to investigate how personalized professional learning would impact educators' instructional practices, which lead to improved students' PL experiences.

Supporting Infrastructure at System Level

The increasing use of online learning systems and other technologies in naturalistic learning settings opens up opportunities to collect, aggregate, share, and analyze not only student performance data but also massive amounts of real-time student learning activity data (Basham et al., 2017; Connell, Johnston, et al., 2017). To better tap into technology and data to personalize learning, more attention in the field should be paid to designing, developing, and implementing technology-based data systems that work across platforms seamlessly, are accessible to all stakeholders (including students), and offer not only timely but also actionable feedback about student learning to improve instructional practices and student achievement (U.S.

Department of Education, 2016). A school-wide technology infrastructure offers affordance for building a robust assessment system that can be embedded in learning activities (Bingham et al., 2016). It is expected that schools implementing PL can use technology-based platforms to support just-in-time assistance, measure student competencies, deliver universally designed resources, and eventually integrate the two based on ongoing assessment of student performance and needs (U.S. Department of Education, 2016).

Data do not drive personalization; the data simply fuel the decision-making process. Unfortunately, the education system has a long history of using data to support inequalities (Zhao, 2016). Modeling data systems on current societal and institutional dispositions will only serve to intensify these inequalities. Moreover, replacing the human with an algorithm, without transparency and oversight, is cause for alarm. Increasing the amount of student data has already raised increasing concerns about student privacy (U.S. Department of Education, 2012). The field lacks transparency of what student data should be collected, how these data are utilized for continuous improvement, and who is permitted access to these data (Bulger, 2016). This means data collection, storage, access, and use for modeling PL require a system of governance with standards, rules, and procedures to ensure data security and student privacy. Students and parents should have a right to know how and why decisions are made both within these digital systems as well as in real-world learning environments. Understanding the how and why of decisions support transparency across stakeholders increases more self-determined learners and encourages greater equity across the education system.

Limitations

This literature review has two limitations that are worth noting. First, the current review followed the same literature search procedures as our previous study. Thus, like our previous study, we did not conduct the quality check for the included studies for the sake of avoiding losing information due to the emerging nature of the field. Second, the empirical PL practices that were mapped onto the framework of UDL in this review were identified from quantitative, qualitative, or interdisciplinary studies. This means that although our previous review found most quantitative and interdisciplinary studies reported positive impacts of PL practices on student educational outcomes, readers should be cautious when interpreting the effectiveness of those PL designs.

Conclusion

PL is a complex phenomenon, which requires systematic support to operationalize its design and implementation. In this sense, PL implementation would benefit from a unifying framework that offers a basis of instructional design considerations for supporting learner variability and dynamic development of all learners. Therefore, this literature review analyzed the current PL designs and implementation practices across disciplines from the lens of UDL. This synthesis of PL from the lens of UDL provided an overview of emergent trends and gaps in designing for supporting learner variability. In addition, the identified contextual factors that would impact PL implementation also provided implications for future research and practice.

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Table 1

Checkpoints of Universal Design for Learning (UDL) in Personalized Learning (PL) Research

Reference	Checkpoints of UDL Guidelines																													
	Representation											Action & Expression									Engagement									
	1.1	1.2	1.3	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	4.1	4.2	5.1	5.2	5.3	6.1	6.2	6.3	6.4	7.1	7.2	7.3	8.1	8.2	8.3	8.4	9.1	9.2	9.3
Group A1 (n =22): Examined effects of adaptive technologies, assessments, or strategies that supported PL																															
• *Web-based adaptive learning systems or intelligent tutoring system*																															
Alcoholado et al. (2011)										×											×									
Arroyo et al. (2014)			×					×		×	×	×					×				×	×				×	×	×			×
Chen (2008)																									×					
Chen (2009a)																									×					
Chen (2009b)																				×				×	×	×	×	×		×
Cornelisz & van Klaveren (2018)										×															×					
Kurilovas et al. (2015)																									×					
Siddique et al. (2017)										×															×					
Siddique et al. (2019)									×	×	×														×		×			
Su et al. (2006)																									×					
Tseng et al. (2008)																									×					
Wang (2014)										×															×					
• *Educational Computer Games*																															
Hwang, Sung, et al. (2012)																									×					
Katsionis & Virvou (2008)										×															×	×	×			
Martín-SanJosé et al. (2014)																					×				×					
• *Robotic Systems*																															
Baxter et al. (2017)										×																×				
Leyzberg et al. (2018)																									×					
Ramachandran et al. (2019)										×																				
• *Virtual Reality System*																															
Bhattacharjee et al. (2017)																									×		×			
• *Computerized Adaptive Assessment*																															
Hammerschmidt-Snidarich et al. (2019)																									×	×				
You et al. (2019)																				×					×					×
• *Flexible small-group instructional activities*																															
Connor et al. (2018)																									×	×				

Table 1 (Continued)

Checkpoints of Universal Design for Learning (UDL) in Personalized Learning (PL) Research

Reference	Checkpoints of UDL Guidelines																														
	Representation												Action and Expression									Engagement									
	1.1	1.2	1.3	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	4.1	4.2	5.1	5.2	5.3	6.1	6.2	6.3	6.4	7.1	7.2	7.3	8.1	8.2	8.3	8.4	9.1	9.2	9.3
Group A2 (n = 18): Examine effects of learner preference/interest-based personalization strategies																															
• *Technology-enhanced context personalization (n =9)*																															
Bernacki & Walkington (2018)																							×								
Çakır & Şimşek (2010)																							×								
Chen & Liu (2007)																							×								
Clinton & Walkington (2019)																						×	×								
Høgheim & Reber (2015)																						×	×								
Kim et al. (2019)																						×	×			×					
Ku et al. (2007)																							×								
Walkington (2013)																							×								
Walkington & Bernacki (2019)																							×								
• *Context personalization involving no modern technology (n = 5)*																															
Akinsola & Awofala (2009)																							×								
Awofala (2014)																							×								
Kucirkov et al. (2014)									×														×								
Şimşek & Çakır (2009)																							×								
Walkington & Bernacki (2015)																							×								
• *Learner-selected learning materials (n =2)*																															
Choi & Ma (2014)																						×									
Ertem (2013)	×																					×	×								
• *Culturally relevant approaches (n =2)*																															
Mottram & Hall (2009)																							×								
Worthy et al. (2012)																						×	×				×				

Table 1 (Continued)

Checkpoints of Universal Design for Learning (UDL) in Personalized Learning (PL) Research

Reference	Checkpoints of UDL Guidelines																													
	Representation												Action and Expression									Engagement									
	1.1	1.2	1.3	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	4.1	4.2	5.1	5.2	5.3	6.1	6.2	6.3	6.4	7.1	7.2	7.3	8.1	8.2	8.3	8.4	9.1	9.2	9.3
Group A3 (n = 8): Explore how ubiquitous and/or mobile learning systems supported PL and their impacts on student educational outcomes																															
Chen & Li (2010)											×												×			×					
Chu et al. (2010)											×												×								
Hartnell-Young et al. (2008)																							×								
Hsu et al. (2013)																							×			×	×				
Hwang et al. (2010)											×												×								
Hwang, Tsai, et al. (2012)									×		×												×								
Looi et al. (2009)											×				×							×	×				×				
Song et al. (2012)									×						×			×			×	×	×								×
Group A4 (n = 2): Explored how non-adaptive technologies facilitated PL implementation																															
• *Learning Management Systems*																															
Edmunds & Hartnett (2014)																		×			×					×					×
• *Multimedia tools for digital storytelling*																															
Kaminskienė & Khetsuriani (2019)																							×				×				
Group B1(n = 4): Explore characteristics of PL environments and their impacts on student outcomes																															
Abawi (2015)											×			×				×	×			×		×		×			×		
Basham et al. (2016)								×							×			×			×	×							×		×
Iver (2011)																															
McClure et al. (2010)																															
Group B2 (n = 3): Explore specific approaches to implementing school-wide PL																															
DeMink-Carthew et al. (2017)																		×				×	×								
DeMink-Carthew & Netcoh (2019)								×										×	×	×	×	×					×				×
Netcoh (2017)																		×				×									

Table 2

Personalized Learning (PL) Designs or Strategies Aligned to Universal Design for Learning (UDL)

UDL Guidelines	PL Research Aligned with Checkpoints of UDL Guidelines
Principle 1: Provide Multiple Means of Representation	
G1: Provide options for perception	1.1 Computer presents learning texts with choice of background color, font style, and picture (Ertem, 2013) 1.2 NA 1.3 ITS systems blend an auditory/verbal with a visual/spatial component of mathematics fluency (Arroyo et al., 2014)
G2: Provide options for language and symbols	2.1 NA 2.2 NA 2.3 NA 2.4 NA 2.5 Provide multimedia information access (Arroyo et al., 2014); Student choose media (e.g. video, web resources, books) to gain information, explore, or research (Basham et al., 2016; DeMink-Carthew & Netcoh, 2019)
G3: Provide options for comprehension	3.1 **(Mobile learning)** Link the scientific theories learned from the textbooks with those authentic phenomena learned from field trip in mobile learning (Hwang, Tsai, et al., 2012); Use KWL within a mobile learning system to activate student prior knowledge (Song et al., 2012); **(ALS)** Present logical details of concept and connect it with previously learned materials (Siddique et al., 2019); Customize components of books based on students' previous experiences by involving familiar contexts and names (Kucirkov et al., 2014); 3.2 **(ALS/ITS)** Provide synchronized sound, animations, contiguous explanations using the math problem space (e.g., underlining, drawing on the figure), and videos that show instructors solving problems and graphically provides virtual pencils to support student problem solving with their own notes (Arroyo et al., 2014); Provide color variations to underline important parts of the concepts (Siddique et al., 2019) 3.3 **(ALS/ITS)** Providing customized scaffolds, hints or feedback (Alcoholado et al., 2011; Arroyo et al., 2014); Allow students advance to the next knowledge type level when the current level is sufficiently mastered (Cornelisz & van Klaveren, 2018); Provide sequentially ordered chunks of information using illustrations (Siddique et al., 2017) and immediate individualized feedback with messages conveying the reasons behind mistake and asking to reattempt (Siddique et al., 2019); Provide adaptive annotations of e-learning materials students need to focus on (Wang, 2014) **(Computer game)** Animated agents lead students to lessons that needs to repeat (Katsionis & Virvou, 2008) **(Robotics)** Adapt length of time between successive moves and progressively release learning information (Baxter et al., 2017); Verbally provide hints at the child's request (Ramachandran et al., 2019)

	(Mobile learning) Detect learner location by RFID, provide adaptive guidance or hints to find the target learning objects in nature science classes, and/or deliver supplementary learning materials (Chu et al., 2010; Hwang et al., 2010; Hwang, Tsai, et al., 2012); Deliver recommended vocabulary learning materials based on student location and knowledge level (Chen & Li, 2010); Provide multiple entry points and learning paths in mobile learning (Looi et al., 2009) **(Teachers)** model thinking processes via their "think aloud" strategies and concept maps (Abawi, 2015) 3.4 Provide "help fading" function that gives students math problems of similar difficulty to encourage them to transfer and perform problems without the need of help (Arroyo et al., 2015)
Principle 2: Provide Multiple Means of Action and Expression	
G4: Provide options for physical action	4.1 NA 4.2 Use assistive technologies as an additional support mechanism in classrooms (Abawi, 2015)
G5: Provide options for expression and communication	5.1 Support multiple means of demonstrating understanding by using multiple tools in PL environments (Basham et al., 2016); (Mobile learning) Offer options to create versatile and multi-modal (picture or text) products (Song et al., 2012; Looi et al., 2009) 5.2 NA 5.3 (ITS) Provide "help fading" function to gradually reduces math learning support until students demonstrate mastery (Arroyo et al., 2015)
G6: Provide options for executive functions	6.1 **(Mobile learning)** Guide appropriate goal-setting by using e-ORDER that consists of enculturation, observation, reflection, data collection and conceptualization, experimentation, and evaluation as six cyclical stages of an experiential learning model (Song et al., 2012); Support students to post learning goals and success criteria in the **(LMS)** to identify their individual needs (Edmunds & Hartnett, 2014) **(Human-mediated)** Use I Can statements to guide goal-setting (Basham et al., 2016); Students set individual learning goals–initially with guidance and then independently (Abawi, 2015); Guide goal setting through independent design, interest driven codesign, interest and skill driven co-design, skill driven co-design, and selection (DeMink-Carthew et al., 2017); Conference with students to provide feedback and support students in goal setting (DeMink-Carthew & Netcoh, 2019); Students write a learning plan for their inquiry, the potential products, possible resources, and their learning goals (Netcoh, 2017) 6.2 **(Teachers)** Support students in planning and acting to achieve goal, and to persist until goals are achieved (Abawi, 2015); Co-plan with students and provide feedback on their planning tools (DeMink-Carthew & Netcoh, 2019)

	6.3	**(Teachers)** Curate resources and offered minilessons on research and note-taking skills (DeMink-Carthew & Netcoh, 2019)
	6.4	**(ALS/ITS)** Provide timely feedback reports on students' learning process to involve students in developing self-evaluation and self-efficacy (Arroyo et al., 2014; Chen, 2009b; You et al., 2019) **(Mobile learning)** Support self-reflection (via Worksheets on mobile devices; Song et al., 2012); **(Teachers)** Provide formative assessment, feedback, and/or self-assessment strategies, tools (e.g., progress trackers) in student-teacher conferences to support monitoring progress (Basham et al., 2016; DeMink-Carthew & Netcoh, 2019) or post questions in LMS to invite student self-reflection (Edmunds & Hartnett, 2014)
Principle 3: Provide Multiple Means of Engagement		
G7: Provide options for recruiting interest	7.1	Optimize individual choice and autonomy over learning such as what to investigate and demonstrate, working at their pace, working independently or in groups (Abawi, 2015; Alcoholado et al., 2011; Basham et al., 2016; Kim et al., 2019; Looi et al., 2009; Song et al., 2012; Worthy et al., 2012); Provide autonomy in the sequence of learning contents (Arroyo et al., 2014; Martín-SanJosé, 2014); Provide autonomy in improvisation to create meaningful contexts (Looi, et al., 2009); Allow student to choose which mathematic task topics based on interest (Clinton & Walkington, 2019; Høgheim & Reber, 2015); Incorporate learner-selected vocabulary into learning content (Choi & Ma, 2015); Allow for customization of online learning texts with choice background color, picture, font style (Ertem, 2013); Increase autonomy over learning through interest- and skill-driven goal setting or choice provision (DeMink-Carthew et al., 2017; DeMink-Carthew & Netcoh, 2019; Netcoh, 2017)
	7.2	**(Mobile learning)** Provide authentic learning experience and evoke curiosity by field trip or going out of the classroom supported by mobile devices (Chu et al., 2010; Hwang et al., 2010; Hwang, Tsai, et al., 2012; Looi et al., 2009; Song et al., 2012); Detect learner location by wireless positioning techniques and deliver recommended vocabulary learning materials based on location to support context-aware learning (Chen & Li, 2010); Provide reading materials based on student preferences supported by mobile devices (Hsu et al., 2013); Provide students mobile phones that help capture their daily life by taking pictures and filming videos as a way to tell their stories (Hartnell-Young & Vetere, 2008) **(Learner-preference personalization)** Incorporate personal interest and or preference into math learning materials (Akinsola & Awofala, 2009; Awofala, 2014; Bernacki & Walkington, 2018; Çakır & Şimşek, 2010; Clinton & Walkington, 2019; Chen & Liu, 2007; Høgheim & Reber, 2015; Ku et al., 2007; Şimşek & Çakır, 2009; Walkington, 2013; Walkington & Bernacki, 2015; Walkington & Bernacki, 2019); Leverage digital story telling multimedia tools to promote and integrate students' unique, personal backgrounds into learning process (Kaminskienė & Khetsuriani, 2019); Provide leveled texts tapping into student interest (Kim et al., 2019); Customize components of books or online texts based on students' interests and likes (Ertem, 2013; Kucirkova et al., 2014); Connects learning with interests, talents, passions, and aspirations through interest-driven goal setting (DeMink-Carthew et al., 2017); Provide culturally

	relevant instruction by taking into account students' interest, personal experiences, and cultural identity (Mottram & Hall, 2009; Worthy et al., 2012); 7.3 Provide sense of acceptance, protections, and inclusion, such as providing safe and quiet places and a time out system of card trade-ins as a non-intrusive, non-threatening means of "escape" from stressful situations (Abawi, 2015)
G8: Provide options for sustaining effort and persistence	8.1 Display the target learning time and target achievement indexes of self-regulation learning competence indicators to support learners self-monitor goal setting (Chen, 2009b) 8.2 **(ALS/ITS/Adaptive Assessment systems)** Provide authentic, near optimal, or adaptive learning paths, contents, and objects based on learners' abilities, prior knowledge, learning styles, etc. (Arroyo et al., 2014; Chen, 2008; Chen, 2009a; Chen, 2009b; Chen & Li, 2010; Hsu et al., 2013; Katsionis & Virvou, 2008; Kurilovas et al., 2015; Martín-SanJosé et al., 2014; Siddique et al., 2017; Siddique et al., 2019; Su et al., 2006; Tseng et al., 2008; Hwang, Sung, et al., 2012; Hammerschmidt-Snidarich et al., 2019); Learning systems automatically return exercises that are slightly more difficult than the student's current understanding level (Cornelisz & van Klaveren, 2018) or items that students need additional practices (Wang, 2014; You et al., 2019); **(Virtual Reality)** Customize learning path with which students can interact constantly (Bhattacharjee et al., 2017); **(Robotics)** Automatically sequences learning content to best suit the skill competencies of an individual student by challenging him or her with the translation tasks that need to be practiced on most (Leyzberg et al., 2018) **(Teachers)** Group students according to their identified needs, and then design learning activities with links to learning resources in the LMS (Edmunds & Hartnett, 2014); Grouped students according to learning needs into flexible learning groups, which were matched with students' areas of strengths and weaknesses (Connor et al., 2018); Provide flexible structures for student learning and prioritize resource allocation based on student needs (Abawi, 2015); Allow for leveled, personalized literacy texts tapping into student prior knowledge (Kim et al., 2019) 8.3 **(Mobile/Multimedia tools)** Foster interactivity and collaboration among students to share artifacts (Looi et al., 2009) or reading annotation/notes supported through mobile devices (Hsu et al., 2013) or to achieve goals using multimedia tools (Kaminskienė & Khetsuriani, 2019); **(ALS/ITS/Robot)** Use virtual companions to promote students' sense of collaboration (Arroyo et al., 2014; Chen, 2009b; Katsionis & Virvou, 2008); Robot act as learning companions to enhance social interaction with learners (Baxter et al., 2017) **(Human-mediated)** Students collaborate with peers and the teacher to plan how to demonstrate their products to the community (DeMink-Carthew & Netcoh, 2019); Students work with peers completing appropriate learning activities when not working with the teacher (Connor et al., 2018); Student pairings (learner and helper) worked together throughout the self-paced activity (Hammerschmidt-Snidarich et al., 2019); Students were encouraged to engage in peer interactions and social identification as a contributing member of the classroom community (Worthy et al., 2014)

	8.4 **(ITS/ALS/Computer Games)** Provide real-time mastery-oriented feedback or affective supports such as encouragement message and hint (Arroyo et al., 2014; Chen, 2009b; Katsionis & Virvou, 2008); Provide immediate feedback with detailed messages conveying the reasons behind mistake and asking to reattempt (Siddique et al., 2019); ‘ **(Virtual reality)** Generate positive feedback leading students towards attaining the overall class objective (Bhattacharjee et al., 2017)
G9: Provide options for self-regulation	9.1 **(ALS)** Helping learners understand the difference between current and target self-regulation indexes, thereby encouraging self-learning motivation (Chen, 2009b); **(Human-based)** Establish high expectations to promote autonomy and motivation by creating PL goals and support goal attainment (Abawi, 2015); Promote expectation and belief through “I Can” statements (Basham et al., 2016); 9.2 NA 9.3 **(ALS/ITS)** Provide timely feedback reports on students’ learning process to involve students in developing self-evaluation and self-efficacy (Arroyo et al., 2014; Chen, 2009b; You et al., 2019) **(Mobile learning)** Support self-reflection (via Worksheets on mobile devices; Song et al., 2012); **(Teachers)** Provide formative assessment, feedback, and/or self-assessment strategies, tools (e.g., progress trackers) in student-teacher conferences to support monitoring progress (Basham et al., 2016; DeMink-Carthew & Netcoh, 2019) or post questions in LMS to invite student self-reflection (Edmunds & Hartnett, 2014)

Note. G = Guideline. NA = Not Applicable; ALS = adaptive learning system; ITS = intelligent tutoring system; LMS = Learning Management System

Table 3

Sample Size and Learner Variability by Research Approach

Description of Variability	**Quan**	**Qual**	**Mixed**	**Total**
No explicit description	12	6	3	21(30%)
Brief description	29	8	4	41(57%)
Detailed description		2		2 (3%)
NA	2	5		7 (10%)
	Included		**Excluded**	
Low-achieving students	5			
Students with special needs	10		1	
Special education teachers	3			

Note. Quan = Quantitative research papers; Qual = Qualitative research papers;

Mixed = Mixed methods research papers; NA = Not applicable

Figure 1

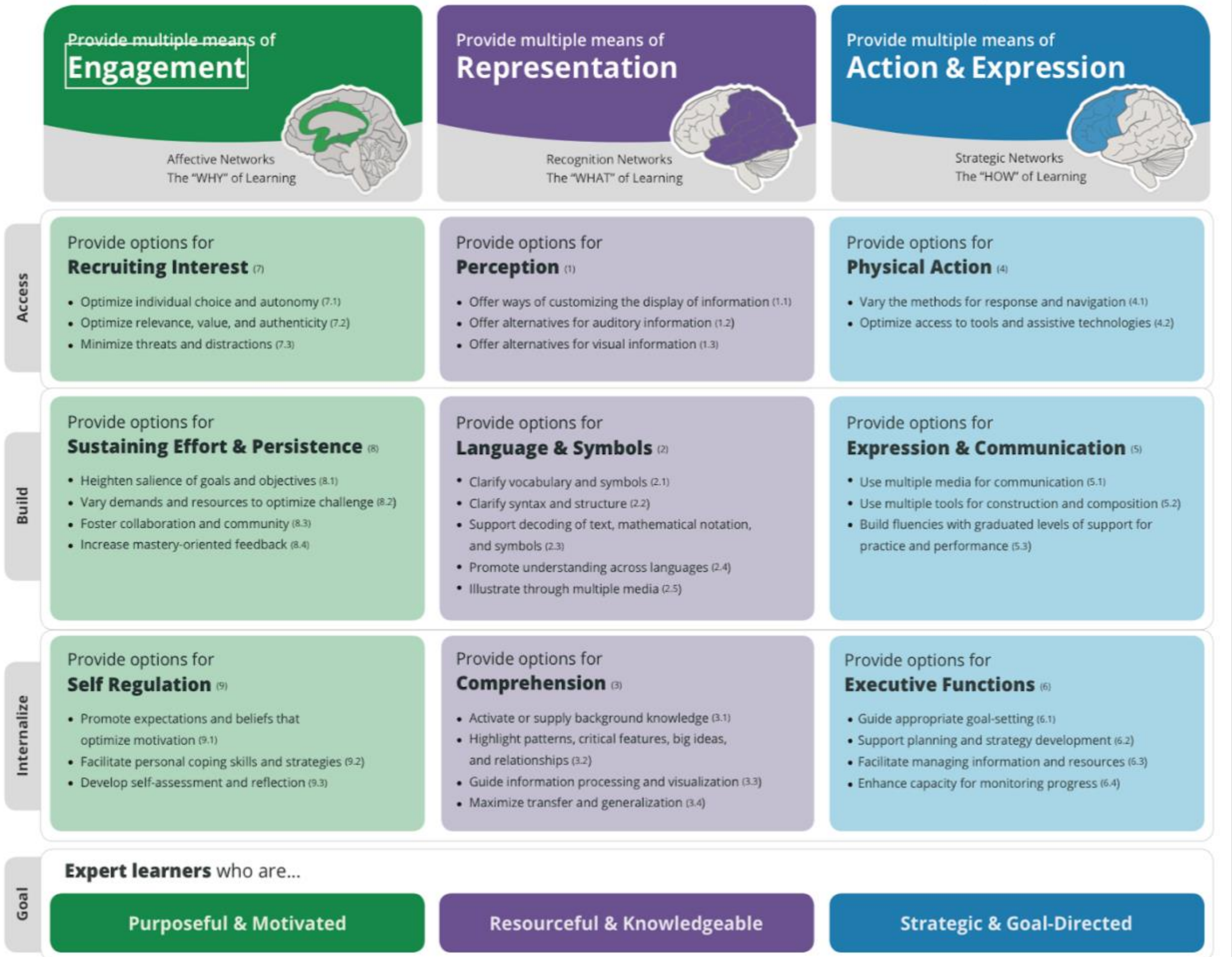

Figure 1. The Universal Design for Learning Guidelines 2.0. The UDL Guidelines is a design framework that consists of three overarching principles and nine guidelines; Under each guideline is a set of specific instructional practices that teachers can use to remove barriers in learning environments to support learner variability; Permission is granted by CAST to use this figure.

Chapter Four: (Re)framing the Measurement of UDL-Based Learning Environments: Develop and Validate the Learner-Centered Sensor

Abstract

The purpose of this study was to develop and content validate a student self-report instrument designed according to the framework of Universal Design for Learning (UDL). This chapter began with a brief introduction into the framework of UDL and a discussion of emergent issues associated with the measurement of UDL implementation. Next, an analysis of why and how to reframe UDL measurement from an alternative perspective was provided. This perspective shifts assessment targets from student performance to learning environment designs. Drawing upon the analysis, this chapter described a conceptual framework for guiding the development of a student self-report tool that can be used to measure UDL-based learning environment designs by detecting barriers to learning from learner perspectives. This chapter then reported on a study investigating the evidence for the content validity of the instrument. Implications and future directions for validating and using the created tool in practices and research were discussed.

Keywords: Universal Design for Learning (UDL); learning experiences; learner perspectives; learning environment assessment; practical measurement

Designing, implementing, and measuring a learning environment (either in a brick-and-mortar, blended, or online format) that supports effective learning experiences for all learners is a complex endeavor. Learning environments are interactive, dynamic physical, social, and pedagogical contexts where learning takes place when learners interact with the learning materials and tools, peers, and teachers (Bell & Aldridge, 2014; Fraser, 1998). These interactions determine whether a learning experience is effective, efficient, and enjoyable (Kirschner, 2015). An individual learner's interactions with the learning environment usually involve neural, experiential, relational, and contextual processes that converge to produce the learner's dynamic (as opposed to linear) development and performance (Cantor et al., 2018; van Dijk & van Geert, 2015). In addition to individual learners' dynamic development, accumulated research from neuroscience, cognitive psychology, and learning sciences has shown that learner variability in terms of learning needs, preferences, interests, and strengths also exist between individuals (see Immordino-Yang & Damasio, 2007; Miller et al., 2002). These within- and between-individual variabilities add another layer of complexity of designing a student-centered environment that tailored to students' diverse learning needs.

As a response to support learner variability, the framework of Universal Design for Learning (UDL) has emerged in research and policy documents as a foundational framework for designing flexible, personalized learning (PL) environments for all learners (Basham et al., 2018; Meyer et al., 2014). The premise of UDL is to reduce barriers existing and emerging from learner-environment interactions through proactive and iterative designs (Meyer et al., 2014). Operationalizing effective designs based on UDL to support learning for all learners involves a multitude of factors. One critical factor is to collect timely feedback on whether the designs meet the diverse learning needs of all learners. Simply put, proactive and iterative designs require implementers to conduct a needs assessment to identify initial design solutions as well as ongoing assessments to detect problems and identify solutions throughout the implementation process (Basham & Marino, 2013). This design-based and problem-solving perspective of UDL implementation requires effective ways to measure the alignment of learning environment designs to the framework.

Enter the Framework of UDL

The UDL framework consists of three overarching principles (i.e., provide multiple means of engagement, multiple means of representation, multiple means of action and expression) as basic considerations for designing a flexible learning environment (CAST, 2018). The three overarching principles guide environmental designs that offer options for how learners engage in learning, access and internalize instructional content, and demonstrate knowledge. Built within the three principles are nine guidelines and 31 checkpoints that offer insights into specific kinds of predictable, systematic learner variability and varying ways to build flexibility in learning environments that supports the variability (Meyer et al., 2014). From an applied perspective, UDL guides proactive and iterative designs for learner variability by tailoring learning goals, assessments, instructional methods, and materials to diverse learning needs in a learning environment (Meyer et al., 2014; Rose & Meyer, 2002). With its focus on the learning environment, UDL aims to reduce barriers to learning and enable the learning environment to adjust to individual learners in a way that they can be empowered to become expert learners (CAST, 2018; Rao & Meo, 2016; Rose & Meyer, 2002).

Measuring the UDL Implementation

Current Instruments and Methods to Measure UDL

An important contributor to the continued development and implementation of UDL that support varying needs of diverse learners involves the availability of valid, reliable measures of both implementation processes and outcomes. Currently, instruments and methods used to examine when and how UDL is effective varied across current research efforts (Cook & Rao, 2018). A majority of empirical studies that applied and evaluated UDL in educational settings examined students' educational outcomes as outcomes of UDL implementation (Ok et al., 2016; Rao et al., 2014). Moreover, a literature review of instruments used in UDL research found that only a few studies reported the fidelity of UDL implementation (Evmenova et al., 2018). The researchers found that educator perceptions and student attitudes, lesson plan reviews, and observation instruments emerged as three major ways to evaluate the alignment of varied educational practices to the framework.

Specifically, most perception measures were researcher-created questionnaires and interview protocols (Evmenova et al., 2018). Only a few studies used modified versions of existing measures (e.g., Attitudes Toward Inclusion) to examine helpfulness and usefulness of UDL-based instructional practices as well as alignment to the framework from educators' and students' perspectives (see Coy et al., 2014; Scott et al., 2015; Van Laarhoven et al., 2007). Several studies on teacher preparation and/or professional development in UDL implementation utilized the original or modified rubric developed by Spooner and colleagues (2007) to gauge the alignment of lesson plans created by participants to the framework (e.g., Courey et al., 2012).

According to Evmenova et al. (2018), most classroom observation tools used to measure UDL implementation were modified from existing rubrics or developed by researchers for the purpose of the study (e.g., Morningstar & Shogren, 2013). An exception is that Basham, Smith, and Satter (2016) created an observation rubric called the UDL Scan Tool drawing upon the framework. The intended use of this observation tool, however, is to examine whether online learning products align with the UDL framework. In addition, Basham and colleagues (2020) developed the UDL Observation Measurement Tool (UDL-OMT) to measure UDL implementation in classrooms.

Reconsidering the Measurement of UDL Implementation

Despite that varied measures were utilized in current UDL studies, researchers in the field have not yet converged on how to effectively measure the implementation of UDL as a design framework (Basham et al., 2020; Cook & Rao, 2018; Smith et al., 2019). Unlike an intervention for a specific group of learners, which would not likely improve outcomes for all students even implemented with efficacy (Cook & Odom, 2013), the fundamental goal of implementing the framework is to support learning for all learners by intentionally considering between- and within-individual variabilities in a given context. Achieving such goal hinges upon design-based processes in which educators proactively and iteratively design learning environments, leading to systematic and sustainable changes. Therefore, UDL implementation requires collecting, analyzing, and utilizing data from multiple sources, including undesirable outcomes, to inform rapid, continuous cycles of improvement (Basham & Blackorby, 2020). In this sense, measuring the implementation of UDL needs to consider the holistic design procedure, specific design components aligned to the framework, and implementation outcomes as reflected by changes in multifaceted educational outcomes for all learners. Certainly, no single instrument suffices to measure the effectiveness or fidelity of implementing the complex, design-based framework.

As Basham and Blackorby (2020) posited, well-designed or poorly-designed implementation of the framework in relation to variables across learner-environment interactions will yield effective or ineffective outcomes, respectively. To determine whether the designs are effective, a validated, robust, integrated measurement system is needed. The system should guide goal setting for implementation outcomes, monitor the design process, gauge the alignment of practices applied in the process to UDL, and evaluate multifaceted learning outcomes. The assessment end should be focused on the designed learning environments. The other incorporated measurements could generate data to support and drive the end goal of assessing UDL implementation. Thus, within the measurement system, the focus is shifted to assessing the learning environment, ideally in a timely fashion. Effective decision making to inform continuous improvement is driven by data, but good decisions made too late are not effective decisions (Redish, 2007). It is then critically important to have “sensors” embedded in the learning environment to measure changes in student learning as responses to changes in factors contributing to environmental designs.

Embedded sensors usually refer to digital devices placed in the physical world that interact with, monitor, and (possibly) effect changes to the environment (Heidemann & Govindan, 2004). In the field of education, embedded sensing has seen an increasing use in collecting vast amounts of data created in the moment-to-moment dynamics of learning activities through human-computer interactions (Preston et al., 2018). Particularly with the advent of wearable sensors (e.g., accelerometers, portable electroencephalograms [EEG] device, eye-trackers), researchers have begun to investigate how data collected from the embedded wearable sensors could help understand teaching and learning processes in face-to-face classrooms (see Preston et al., 2018; Prieto et al., 2016; Prieto et al., 2018). As promising as it sounds in terms of collecting real-time data on individual-in-context activities using sensors, these advanced technological and intelligent data-centric systems are too costly to be affordable for most classrooms. In the following section, therefore, I discussed why and how learners could serve as human “sensors” within a learning environment to collect learning needs data. Drawing upon the discussion, I proposed to develop and validate a student self-report instrument as an alternative sensor that helps collect data to record changes in learning environments.

Measuring UDL by Students Acting as “Sensors” in a Learning Environment

Students who act as human “sensors” need to capture changes in a learning environment. This means that students who are immersed and have firsthand experience in the environment need to evaluate whether environmental designs meet their learning needs. Integrating individual students’ learning experiences data into UDL measurement system holds the promise to inform continuous improvement in designs that support personalized learning for all. Meanwhile, the consideration for incorporating student perspectives in UDL measurement also provides an avenue for students to raise more voices regarding their own learning experiences. Thus, having students to evaluate environmental designs would potentially increase opportunities for students to develop more agency over decision making if their needs reflected through evaluations are addressed and supported in follow-up design processes.

To date, unfortunately, there is no inventory specifically created to measure the UDL implementation from student perspectives. Research in the field, however, has demonstrated a growing need for such an assessment tool that measures alignment to the implementation of UDL. For instance, Abell and colleagues (2011) conducted a study to examine whether students’ perceptions toward instructional design aligned to UDL principles varied in school grade levels. Given the lack of UDL environment assessment tool, the researchers utilized a revised version of the Individualized Classroom Environment Questionnaire (ICEQ; Fraser, 1998) to gather student perceptions. To capture more UDL-centric classroom principles, Abell et al. (2011) modified the original five-factor survey with 50 items and turned it into a three-factor (i.e., Personalization, Investigation, and Participation) survey with 31 items.

The three constructs, to a certain degree, can be used to measure several psychosocial characteristics of a UDL-aligned learning environment. However, the items nested within each construct (e.g., Q1: The teacher considers students' feelings [Personalization]; Q39: Students carry out investigations to answer questions which puzzle them [Investigation]; Q28: Students are punished if they behave badly in class [Participation]) provide ambiguous information on where and how teachers could specifically modify and improve instruction to meet student needs. As indicated by the researchers themselves, there is a need for validated instruments that can measure instructional components specifically aligned to the UDL framework (Abell et al., 2011).

Purpose of the Study

The purpose of this study was to develop a student self-report instrument called the *Learner-Centered Sensor* (hereafter, the *Sensor*). If validated and used effectively, this instrument can collect data on student perceptions of UDL-based learning environment designs in terms of their learning experience. The collected data, in turn, will assist researchers and teachers (as instructional designers) in measuring the extent to which the learning environment designs meet student needs and, more importantly, in gathering information to inform continuous and timely instructional improvement.

Conceptual Framework for Guiding the Development of *the Sensor*

As discussed above, one important characteristic of a UDL-aligned PL environment is that variation should be intentionally designed in teaching and learning activities so as to meet varying student needs. From the improvement perspective, assessments of UDL-aligned learning environments should capture those variations in individual student learning needs in a response domain that signals where improvements in specific instructional designs are needed. Bearing this in mind, I created a conceptual framework based on learning environment assessment and practical measurement, within the framework of UDL, to guide the process of identifying and generating constructs and items for the *Sensor*. In the following section, I describe how the conceptual framework guided the development of the *Sensor*.

Learning Environment Assessment

A learning environment encompasses both physical and psychosocial aspects that would influence how learning occurs. Previous research has investigated various ways to assess the characteristics of a learning environment and their associations with student learning outcomes (e.g., Bell & Aldridge, 2014; den Brok et al., 2006). Typically, external observer ratings, teacher ratings, and student ratings are three main data sources used to assess characteristics of a learning environment (Fraser, 1998). Each measurement perspective has specific methodological and theoretical advantages and disadvantages. From a phenomenological point of view, however, student ratings are viewed as the most reasonable and appropriate data source for evaluating learning environments (Lüdtke et al., 2009). This is because compared to other objective indicators of the learning context, students have the first-hand experience of many different learning environments and their individual interpretation of the context would affect more of their learning behaviors (Bell & Aldridge, 2014; Lüdtke et al., 2009).

Studies utilizing student self-report data have provided consistent and strong support for the predictability of students' educational outcomes by their perceptions of psychosocial characteristics of classrooms even when a comprehensive set of other factors were held constant (e.g., Bell & Aldridge, 2014; Fraser, 2012). This predictive validity of student perceptions offers practical implications for the ways in which teachers might change instructional designs in an attempt to improve student learning (Fraser, 1998). It is important to note that student ratings of the learning environment are often multilevel in nature, comprising of individual perceptions and group perceptions (den Brok et al., 2006). The two-level nature is consistent with what Stern (1970) differentiated between perceptions that individual members have about an environment (idiosyncratic private beta press) and perceptions that members of a group shared about an environment (mutually shared consensual beta press).

A potential problem would occur if researchers and teachers are interested in identifying differences among individual students within a classroom (Fraser, 1998). The idiosyncratic nature of individual perceptions does not allow any conclusions to be drawn about the overall effects of environments, imposing challenges for assessing the reliability of student ratings of environments at the individual level (Lüdtke et al., 2009). Nevertheless, students' individual ratings of learning environment characteristics can be aggregated into averaged scores at the classroom-level that represent the collective perspective of the class as a whole (den Brok et al., 2006; Lüdtke et al., 2009). This multilevel perspective offers a conceptual basis for developing an instrument that is sensitive to variation in individual student perceptions of learning environments at the individual level as well as capable of capturing overall design features of the environment.

Practical Measurement for Improvement

Learning environment measurements can be used as a source of process criteria to evaluate educational innovations and intermediate targets to predict students' cognitive and affective learning outcomes (Fraser, 2012). It is important for researchers and teachers to use those data to assess group perceptions of psychosocial environment characteristics. However, they also need formative data about specific instructional processes and student experience to improve quick outreach efforts (Bryk, 2015). The need for such formative data stimulates the need for an instrument that can be used to gather information on the specificity of instructional activities or learning experiences and thus signal malleable factors to which changes might be introduced to address individual learning needs (Yeager et al., 2013).

Bryk and colleagues (2015) call such instrument practical measure. It is the specificity that makes it possible for practical measures to inform continuous improvement. To guide the development of practical measures, they suggest that the instrument should (1) predict ultimate outcomes of interest; (2) be sensitive to process changes; and (3) provide guidance for subsequent improvement efforts (Bryk et al., 2015). The predictive utility of a well-designed practical measure is consistent with the predictive validity of the aforementioned learning environment assessments on ultimate student educational outcomes. The other two principles focus more on the sensitivity of well-designed measures to short-term changes and their capacity of providing short-term feedback on whether improvement has been made (Bryk et al., 2015; Yeager et al., 2013). Overall, the development of practical measures draws on both solid theories as well as wisdom of practice to guide continuous improvement in practice over time (Yeager et al., 2013).

Combining Environment Characteristics and Instructional Practicality

Both psychometric classroom learning environment assessments and practical measurements can provide valuable information about instructional design. But they are different in terms of assessment purpose and development process. The psychometric assessment focuses on testing relational propositions among key constructs that form certain psychosocial characteristics of a learning environment and may incorporate redundant items to increase the reliability of a scale. By comparison, practical measurement, which attempts to inform continuous improvement, needs to be brief, easily collected, and contextually appropriate so as to be used routinely in educational settings (Bryk, 2015; Duckworth & Yeager, 2015). Data from practical measures should be easily accessible to teachers in a timely fashion to signal student learning needs that are the explicit target of improvement efforts and inform decision making (Duckworth & Yeager, 2015). The advantages of both measurements jointly provide a foundation to create an innovative learning environment assessment that can be used to capture environment design features to predict ultimate educational outcomes and to identify specific learning needs to support continuous improvement at the same time.

By and large, the guiding principle for developing the *Sensor* is to integrate the merits of the two types of measurement, capturing UDL environmental characteristics and informing instructional improvement. Therefore, I created a conceptual framework (see Figure 1) that provides an avenue for developing the *Sensor* from a perspective at the intersection of learning environment assessment and practical measurement for improvement. If validated, the *Sensor* will be able to capture group-level perceptions of UDL learning environment characteristics. Educators, in turn, will be able to use data gathered on the specific *Sensor* items to identify individual student needs on a regular basis to guide improvement on instructional designs.

<Insert Figure 1 About Here>

Based on the conceptual framework, items created for the *Sensor* need to be sensitive to changes that may need to be introduced to support individual student needs. Correspondingly, the items that are nested within the constructs of the *Sensor* need to be descriptors or indicators of student perceptions of teaching and/or learning activities that are likely to be modified and improved over time in ways that maximize student learning (as shown by the orange arrow). The group-level perceptions of the design characteristics reflected by the constructs of the *Sensor* then serve as intermediate targets of UDL implementation to predict ultimate student educational outcomes (as indicated by the dotted line). In the following section, I detail the rationale and procedures of identifying constructs and generating items for the *Sensor* drawing upon the conceptual framework.

Construct Identification and Item Generation

Identifying constructs and generating items for the *Sensor* to capture design features of the learning environment and indicate improvement in instruction requires a better understanding of the framework's design nature first. As suggested by its name, but often overlooked, UDL is fundamentally about designing for learning to support learners throughout different learning processes by making structural changes (Basham & Blackorby, 2020). A desirable outcome of a flexible, dynamic, UDL-based learning environment is to empower all students to become knowledgeable, goal-directed, and motivated expert learners (Meyer et al., 2014). The UDL Guidelines created by CAST is more of a design framework that suggests strategies for implementation than a checklist or template. From a design perspective, instructional practices designed in alignment with the three UDL principles—providing multiple means of engagement, multiple means of representation, and multiple means of action and expression—support learner variability in accessing information, building knowledge, and internalizing learning in a dynamic environment (Basham & Blackorby, 2020; Meyer et al., 2014).

Construct Identification

To be practical, the constructs of the *Sensor* need to cover effective instructional practices that provide specific information when improvement needs to be introduced. According to Meyer et al. (2014), effective instruction from the perspective of UDL consists of four pillars, which are (1) clear, appropriate goals; (2) ongoing, construct-relevant assessment; (3) flexible, adaptive methods; and (4) accessible, engaging materials. Any effective instruction is built upon clearly-defined goals and expectations; however, *UDL approaches to goal setting* also proactively consider learner variability by separating the goals from the means, which allows learners with varying needs and preferences to take different pathways and actions when needed to achieve the goals (Meyer et al., 2014; Rao & Meo, 2016). Drawing upon research on choice making and self-determination (see Patall et al., 2008; Shogren et al., 2004), the UDL approach to learning environment designs also supports learner input in their own personal academic and behavioral goal setting whenever possible. Closely tied to UDL goals, *effective assessments aligned to UDL* provide students with multiple opportunities to demonstrate skills as well as teachers with ongoing actionable information about student learning to inform instruction (Meyer et al., 2014).

Effective *instructional methods from the UDL perspective* support varying learner needs in processing information, interacting with learning materials and tools, planning effective strategies to engage in learning activities, self-monitoring learning progress, and so forth in the process from setting goals to demonstrate learning (Rao et al., 2014). In addition, *UDL instructional practices* emphasize the importance of fostering collaboration and community in a way that can be supportive for all learners (Meyer et al., 2014; Rao & Meo, 2016). As the last critical pillar of UDL instructional design, accessible materials and resources should align closely with the UDL goals and instructional methods so that they support both desired outcomes and learner variability (Basham & Marino, 2013; Rao & Meo, 2016).

From the learners' perspective of the effectiveness of UDL-aligned instruction or learning environments, the outcomes of these macro design considerations around the four pillars need to meet their learning needs. Furthermore, each macro design consists of a set of specific "micro" instructional practices. Given that UDL guides flexible instructional designs to support varied learner-environment interactions, specific instructional practices under each macro design process may vary across contexts. Aligned to the aforementioned pillars, the UDL Implementation and Research Network (UDL-IRN; 2011) proposed four critical elements as a foundation for UDL implementation, which include 1) clear goals, 2) intentional planning for learner variability, 3) flexible learning materials and methods, and 4) timely progress monitoring. That said, although flexible in applying different UDL checkpoints, educators designing learning environments based on UDL need to minimally include each of the four critical elements (UDL-IRN, 2011).

Of the four critical elements, intentional planning emphasizes the proactive design of learning environments that provide flexibility, choice, and engagement that support learner variability. Psychologically, intentionality is a characteristic feature or fundamental property of consciousness (McIntyre & Smith, 1989). Within UDL, intentional planning for learner variability is a complex construct representing a proactive design process carried out by educators and thus is better measured by soliciting educators' design thinking and process. In that regard, it is challenging to measure intentionality from learners' perspectives. From learner perspectives, nevertheless, the outcome of the intentional design is the flexibility embedded across different aspects (e.g., goals, assessments, methods, and materials) of UDL-based environments; these flexible designs help improve student sense of being supported regardless of learning variability in different aspects such as cognition and engagement. As such, clear goals, flexible methods and materials, timely progress monitoring, support learner variability form four necessary characteristics of UDL-based learning environments from learner perspectives. Ideally, the change in these characteristics could be directly sensed by learners.

Additionally, Basham and Blackorby (2020) discuss an effort facilitated by CAST and the UDL-IRN to develop field-based micro-credentials for individuals to demonstrate understanding of UDL. Currently, the Core Credential provides a means to show someone can identify UDL in a learning experience. The Core Credential is driven by seven knowledge statements (see Learning Designed, 2019) that align to the UDL Critical Elements. These knowledge statements include: (1) The goal is presented so learners can perceive and understand the goal; (2) The goal is separate from the means, where possible; (3) The goal is presented to highlight relevance; (4) The goal promotes expert learning by encouraging challenging ways of thinking and doing; (5) The flexible methods are available for learners; (6) The flexible materials are available for learners; (7) There are opportunities for flexible assessment options.

The four UDL instructional pillars, UDL Critical Elements, and UDL Core Credential knowledge statements serve as the conceptual and practical considerations for identifying constructs of the *Sensor*. These concepts and practical considerations are highly related, highlighting clear goals, flexible materials and learning activities, as well as flexible and timely assessments, which serving the supports for learner variability. Thus, the *Sensor* needs to include four constructs (i.e., clear and relevant goals [CRG], flexible instructional methods and materials [FMM], timely progress monitoring [TPM], and supporting learner variability [SLV]) that help capture basic UDL-based environment design features from learner perspectives.

Additionally, the overarching goal of UDL is to prepare all students to become expert learners (CAST, 2018; Meyer et al., 2014). In this regard, Expert Learning was also identified as a construct that represents the fundamental goal of UDL implementation. Compared to other identified constructs, expert learning is a complex and ongoing process of reflection and growth (CAST, 2019). Meyer and colleagues (2014) also indicated that "learning expertise cannot be measured simply by evaluating competencies and outcomes at a single point in time because learning is a process of continual change and growth" (p. 22-23). That said, measuring expert learning is to evaluate the ongoing outcome of students' optimal learning experiences in a UDL-based environment. Therefore, Expert Learning was added as an optional or standalone construct to the *Sensor*, which can be administered with or without the other four constructs. Hypothetically, there exists positive correlations between Expert Learning and the other constructs. Future research is needed to validate the positive correlations between the Expert Learning construct with other existing validated measures.

To provide guidance for targeted improvement in designs, a set of indicators that reflect learners' learning experiences supported by more specific UDL-aligned design strategies is needed for each construct. Creating indicators for each construct also increases the sensitivity of the *Sensor* to learner and context variations given that combinations of indicators representing learning responses to UDL designs can vary across learners and learning contexts. In practice, educators then will have more specific information related to which UDL design variable(s) leads to better student learning behaviors and outcomes.

Item Generation

The UDL Guidelines serve as a framework that offers a set of suggestions for implementing evidence-based instructional strategies and practices (Basham et al., 2018). Thus, unlike other instrument development that drew upon extensive literature review to generate items, the Guidelines itself provides a basis for the *Sensor* item generation. Drawing upon the UDL Guidelines, I created first-person statements (e.g., " I understood the goals of the lesson") to indicate students' optimal learning experiences as would be supported by the outcomes of UDL implementation. Relevant statements were clustered together under each of the three identified macro processes of UDL implementation and formed indicators that mirror salient learning experiences in a UDL-based learning environment. In total, 20 indicators emerged from the nested statements, based on which corresponding evaluation statements were created to solicit student learning experiences. Specifically, four items are nested under the construct *Clear and Relevant Goals*, five under *Flexible Materials and Methods*, six under *Timely Progress Monitoring, and five under Supporting Learner Variability (SLV)*. According to UDL, expert learners refer to learners who are purposeful and motivated, resourceful and knowledgeable, as well as strategic and goal-directed (CAST, 2018). Thus, six items were generated to reflect key learning characteristics a learner might possess if he or she was engaged in *expert learning*.

To sum, the initially proposed student self-report instrument consists of four core constructs and 20 items within a hierarchical structure. The construct *Expert Learning* and six associated items were added as optional to the *Sensor*. It is worth noting that expert learning is such a complex multidimensional construct that assessments of the concept may require a more complex set of indicators than the six items proposed in this study. The purpose of generating the current six items under the construct of Expert Learning was to capture the basic learning traits as an outcome of long-term implementation of UDL. The relationship between the core and optional constructs of the tool will be tested in future research, so is the change in students' expert learning within the context of UDL.

Targeted User Population and Instrument Format

These items were developed for use with students in middle or high schools (i.e., Grade 6-12). The tool was created using an online system, Qualtrics. Each item uses a visual analogue scale (VAS), which is a continuous scale comprised of a horizontal line, usually anchored by 2 verbal descriptors that determine the extent to which raters disagree or agree with the statement (see Zehetleitner & Rausch, 2013). The VARS for the *Sensor* items presents the anchors (e.g., *Disagree* and *Agree*) at the two ends, and students can indicate their perception by marking on a line between the anchors. These marks can be automatically converted into a numerical value from 1 to 10. Slider system was used given that previous research on subjective measures shows it provides a larger amount of information, helps participants be more attentive, and thus increases precision in estimates than do discrete scales (Rausch & Zehetleitner, 2014).

Adopting a two-step argument-based approach (Kane, 2006) to examine the validity of the *Sensor*, I first outline three assumptions to underlie the logic of the intended use and interpretations of the tool. The first assumption is that the *Sensor* items represent learners' optimal learning experiences supported by key UDL-based instructional designs. Second, the proposed structure of the *Sensor* corresponds to four critical elements of UDL implementation. Third, the proposed structure of the *Sensor* applies to varying learning environments for different content areas (i.e., English Language Arts, social studies, mathematics, science); the measurement invariance of the instrument holds across students with different characteristics (i.e., gender, grade level, race/ethnicity). The focus of the present study is to conceptually and empirically justify the five-factor model for the *Sensor* by generating the validity evidence based on its content structure to address the first assumption. Future research is needed to test whether the psychometric properties of the instrument could substantiate the second and third assumptions.

Method

To evaluate the first assumption about the *Sensor*, this study was designed to test its content validity. Content validity refers to "the degree to which an instrument has an appropriate sample of items for the construct being measured" (Polit & Beck, 2006, p. 423). Content validation is a critical early step in developing and improving the instrument before conducting studies to assess other psychometric properties (Polit et al., 2007; Rubio et al., 2003). The validation process allows researchers to gather information on the clarity, relevance, and comprehensiveness of an instrument that is conceptually defined by these items based on content experts' judgement (Rubio et al., 2003).

Establishing content validity evidence includes quantifying the degree of agreement of experts' ratings on the extent to which items are clear or relevant to the definition of constructs of a survey being measured (Polit & Beck, 2006; Gajewski et al., 2012). Expert ratings of item clarity or relevance can generate two types of content validity index (CVI)—item-level (I-CVI) and scale-level index (S-CVI; Polit & Beck, 2006). I-CVI represents experts' ratings of clarity or relevance of individual items to the underlying constructs; S-CVI represents the proportion of items on an instrument that were rated to be quite or highly relevant (Polit & Beck, 2006). In addition, qualitative data on experts' feedback on comprehensiveness of the items to measure the underlying constructs were collected during the validation process in the present study.

Participants and Recruitment Procedure

Purposive sampling was used to recruit a panel of UDL experts from CAST and UDL-IRN, two organizations that help lead the growth and development of UDL. Specifically, a request for participation was emailed to eight potential experts in November 2019. Alongside the email, a consent form that included the purpose of the study, a description of the *Sensor* and its scoring, as well as an explanation of how to rate the *Sensor* items were sent to the potential participants. Experts were also notified that they might be contacted again to examine the revised measure if major revisions would be made after the first round of data analysis. Prior research suggests that a minimum of three experts is acceptable for a content validation effect (Polit et al., 2007). In the present study, a panel of seven experts (including three females and four males; six Caucasians and one person of color) replied and participated in the study. Of the seven experts, five were academic professors affiliated with research institutions and UDL-IRN and had actively engaged in UDL research. One was a senior researcher from CAST with expertise in UDL measurement and implementation. The other expert was a UDL implementation consultant with extensive experience in UDL implementation. All experts had published referred articles and/or books on UDL.

Measure

A CVI survey (see Appendix A) was created and utilized in the present study to collect data on experts' evaluation of clarity, relevancy, and comprehensiveness of the *Sensor* items to measure the five proposed domains that conceptually represent students' learning experiences supported by key characteristics of UDL implementation. The CVI survey was then converted to an online format using Qualtrics and distributed to the experts who confirmed participation in the study. Quantitative data were collected through the CVI survey on experts' ratings of clarity and relevance of each item to the underlying constructs. Experts were asked to rate each item on a 4-point Likert scale, with "1" indicating "item is not clear" or "item is not relevant to the construct" and "4" indicating "item is clear" or "item is relevant to the construct" (Rubio et al., 2003). Text box was provided after each item for experts to provide feedback or suggestions on how to improve the item. Additionally, one open-ended question was included after each construct to ask experts to evaluate the comprehensiveness of the sampled items by either adding or deleting items.

Data Analysis

Quantitative ratings on clarity or relevancy were analyzed to compute both I-CVI and S-CVI scores. I-CVI was calculated by dividing the number of experts who rate either 3 or 4 on the 4-point scale by the total number of experts; S-CVI is calculated by averaging I-CVI across items (Polit et al., 2007). According to Polit and colleagues (2007), an I-CVI of .78 or higher indicates an excellent level of content validity regardless of the number of experts. Items with an I-CVI lower than .78 would be considered for revision; items with very low I-CVI would be considered for deletion. A S-CVI of 0.80 was considered as the lower limit of an acceptable S-CVI. As suggested by Pilot et al. (2007), the goal for a scale to be judged as having an excellent S-CVI calculated by averaging I-CVI across items should be 0.90.

Moreover, reliability or interrater agreement, an indication of the extent to which the experts were reliable in their ratings, was calculated for item relevance and clarity as a supplement to CVI (Rubio et al., 2003). Specifically, the Kappa coefficient of agreement (i.e., a measure of agreement that adjusts for chance agreement; Zamanzadeh et al., 2015) was utilized to evaluate the interrater agreement on relevance and clarity of the *Sensor* items. The Kappa coefficient was calculated using the following formula: Kappa = (I-CVI -Pc)/(1-Pc), where Pc=[N!/A!(N-A)!]*0.5N, which indicates the probability of chance agreement, N = number of experts, and A = number of experts who agree that the item is clear or relevant. A Kappa value above 0.74, between 0.60 and 0.74, or between 0.40 and 0.59 is considered to be excellent, good, and fair in terms of reliability (Zamanzadeh et al., 2015).

Qualitative data collected from experts' comments on individual items, coupled with I-CVI and Kappa coefficient for clarity and relevance, were analyzed to inform whether item revisions were needed. In addition, experts' open-ended responses to the comprehensiveness of each construct (e.g., the extent to which the items represent the content domain adequately) were analyzed to identify commonalities among experts' feedback to inform whether addition or deletion of items was needed.

Results

Calculations of the I-CVI and Kappa coefficient for each item were provided for clarity and relevance. In addition, S-CVI was calculated by averaging I-CVI across items nested within each construct (i.e., Clear and Relevant Goals, Flexible Methods and Materials, Flexible and Timely Assessments, Supporting Learner Variability, Expert Learning) as well as across all items of the *Sensor*. Table 2 to 6 show results of experts' ratings on clarity, relevance, I-CVI, and reliability statistics of items nested under each construct, respectively.

Content Validity Index

Of the 25 items, 20 items were scored "3" or "4" by all experts on its relevance to the construct being measured, yielding an I-CVI of 1.00. Each of the remaining four items (e.g., Item 3, 10, 11, 17) was scored below "3" in terms of relevance by one expert (I-CVI = 0.86), respectively. Items 10 and 11 were rated "1" by one expert, which indicates potential changes to these items might be needed to improve the CVI. Overall, the CVIs for item relevance ranged from 0.86 to 1, indicating an excellent level of content validity for relevance across all items. In addition to I-CVI for individual items, calculations of S-CVI generated an excellent level of relevance for each construct, that is, 0.95 for Clear and Relevant Goals, 1.00 for Flexible Methods and Materials, 0.94 for Flexible and Timely Assessments, 0.98 for Expert Learning, and

1.00 for Supporting Learner Variability. Averaging S-CVI across constructs yielded a S-CVI of 0.97 for relevance of the instrument. Both I-CVI and S-CVI suggest an excellent level of relevance of the sampled items and underlying constructs of the *Sensor*.

Expert ratings on item clarity generated I-CVIs ranging from 0.71 to 1.00 across all items. Specifically, two items (item 3, 12) received two expert ratings below 3 on its clarity, yielding an I-CVI of 0.71, indicating necessary revisions were needed. Five items (item 4, 8, 17, 23, 24) were rated below "3" by one expert, producing an I-CVI of 0.86 for clarity. The remaining items were scored "3" or "4" by all experts. At the construct level, the S-CVI for Clear and Relevant Goals, Flexible Methods and Materials, Flexible and Timely Assessments, Expert Learning, and Supporting Learner Variability is 0.86 (acceptable), 0.95 (excellent), 0.94 (excellent), 1.00 (excellent), and 0.89 (acceptable), respectively. Calculating the S-CVI across constructs yielded a S-CVI of 0.93 for clarity of the instrument, reaching an average excellent level of clarity of the *Sensor* items.

Interrater Reliability

As shown in Table 2 to 6, Kappa coefficients for both relevance and clarity were computed for each item. Calculations of interrater reliability of expert ratings on item relevance adjusted for chance yielded a Kappa value of 0.85 (> 0.74) for four items (item 3, 10, 11, 17) and 1.00 for the remaining items. According to previous research (Pilot et al., 2007; Zamanzadeh et al., 2015), the interrater reliability of expert ratings on relevance of each item is deemed as an excellent level of agreement. Similarly, computing interrater reliability for item clarity yielded a Kappa value of 0.65 for item 3 and 12, which is considered as a good level of agreement adjusted for chance. Additionally, all the remaining items received a Kappa value of 0.85 or 1.00, which is viewed as an excellent level of interrater reliability for clarity adjusted for chance.

Item Revision

Overall excellent levels of I-CVI and S-CVI for item relevance suggested retaining all 26 items on the instrument. The two items (item 3 and 12) with lower than acceptable levels of I-CVI for clarity were subjected to revisions. Drawing upon expert feedback, the items were changed from "*The lesson went along with my interests*" and "*When I don't understand during the lesson, my teacher provides me ways to understand*" to "*The lesson included things that interest me*" and " and "*When I don't understand during the lesson, my teacher provides me other ways to understand.*" To further improve clarity, five items were reworded after analyzing both I-CVI and expert feedback. Specifically, items 2, 8, and 23 were rated "3" (i.e., item needs minor revisions to be clear) and "2" (i.e., item needs major revisions to be clear) at least once, respectively. Additionally, although with an excellent level of content validity for clarity (i.e., I-CVI = 1.00), items 7 was rated "3" by five experts, and item 18 rated "3" by three experts. Minor changes were made to each of these items based on expert feedback. For example, item 7 was changed from "*There were multiple ways I learned during the lesson*" to "*I was able to learn in multiple ways during the lesson.*"

Overall Comprehensiveness and Readability

Analyzing experts' feedback on the comprehensiveness of each construct revealed two types of suggestions. First, experts suggested adding one item to solicit whether students had opportunities to self-reflect on goal achievement or learning progress. However, item 14, "*I was provided opportunities during the lesson to check my progress along the way,*" was developed to measure self-monitoring as part of self-regulation. Thus, no item was added in order to keep the number of items short. Another suggestion offered by one expert across constructs was to add items asking students which choice of materials, means of how they learned, or strategy was most beneficial to their learning. This suggestion offered implications for future research and practice, which would be discussed in the Discussion section. As a result, no item was deleted or added to the final version of the Sensor.

A free readability test tool (see https://www.webfx.com/tools/read-able/check.php) was used to calculate the readability of the Sensor items. The calculation produced key scores such as Flesch-Kincaid reading ease and grade level that equals to the U.S. school grade level. The results show that the Sensor items have an average grade level of about 5, indicating that they should be easily understood by 10- to 11-year-old students. After the readability testing, the revised tool was emailed to the same panel of experts to seek consensus and affirmation on the established content validity. Three experts responded to the email and affirmed the changes made to the instrument.

Discussion and Conclusion

Implementing UDL to design inclusive, innovative, and personalized learning environments requires timely and ongoing assessments of whether the environmental designs meet individual learners' needs. This chapter reported on the development and content validation of the Learner-Centered Sensor that can be used to measure student learning experiences in a UDL-aligned learning environment. The conceptual framework that guided the instrument development was at the intersection of research on learning environment assessment and practical measurement for instructional improvement. Construct identification and item generation were mainly situated within the framework of UDL. More specifically, the *Sensor* consists of four core constructs (i.e., Clear and Relevant Goals, Flexible Methods and Materials, Flexible and Timely Assessments, and Supporting Learner Variability) that align to the critical elements of UDL implementation as well as one optional construct (i.e., Expert Learning) that represents one fundamental goal of UDL implementation. There are 26 items nested under the five constructs.

The content validation yielded excellent CVIs for item relevance and good to excellent CVIs for item clarity of the *Sensor*. On average, all constructs have an excellent level of CVI for item relevance and clarity. High interrater reliability scores across all items demonstrated excellent levels of expert agreement on relevance and clarity adjusted for chance agreement. Minor changes were made to seven items with relatively low CVIs for clarity based on expert suggestions for improving the language. Additionally, the instrument has a readability grade level of 5. In the following section, limitations of the study were acknowledged, followed by a discussion of implications for future research and practice.

Limitations

There are several limitations to this study. First, it is acknowledged that the development of the Sensor constructs and items was guided by the review of research on UDL implementation and measurement. However, researchers have suggested that instrument developers should carefully consider voices or perspectives of key informants, such as those on whom the instrument will be administered, during the initial phase of instrument development (Onwuegbuzie et al., 2010). With regard to the Sensor instrument, students are the direct users. During the development phase of the present study, only four middle or high school students were asked for feedback on item clarity before the instrument was sent to experts for content validation. To address the limitation, more research is needed to investigate utility and feasibility of the proposed instrument from students' perspectives. For example, Onwuegbuzie and colleagues (2010) recommend instrument developers conduct interviews, focus groups, and direct observations to gain emic perspectives, which may help revise and refine instruments.

Additionally, it should be noted that experts' ratings and feedback are subjective by nature. While Kappa coefficients were calculated to estimate agreement among experts adjusted for chance, the results of the study are subjected to bias that may exist among the experts. As described subsequently, more research is needed to estimate psychometric properties of the instrument.

Implications for Research

Findings of this study showed the evidence on content validity of the student self-report instrument. Nevertheless, establishing content validity is only the first step of instrument validation process. Additional research is needed to evaluate reliability, construct-related validity, and criterion-related validity of the instrument (AERA et al., 2014). The development and content validation processes presented in this study provide several directions for further validating the instrument.

First, the proposed structure of the instrument needs further validation based on more empirical evidence. It is important to note that UDL is a complex instructional design framework. As described earlier, UDL-based designs may vary based on varying student needs across environments (Basham & Blackorby, 2020). The constructs of the Sensor were proposed by taking into account the complexity and flexibility of UDL implementation, aiming to help capture students' responses to critical instructional design features aligned to UDL. Thus, future validation research that test the factorial structure of the instrument is needed. Additionally, given UDL is premised on meeting all learners' learning needs, an instrument with an intended use to evaluate whether learning needs are met within a UDL-design environment should be applicable to all learners. This makes critically important to test if measurement invariance holds for all learners, regardless of race/ethnicity, gender, (dis)ability status, and other characteristics of learner variability, across varying contexts in future research.

Another consideration for developing the instrument was focused on its utility in signaling areas of instructional improvement from student perspectives. As such, research is needed to test the assumption that the *Sensor* possesses validity to predict the effects of student ratings of the key UDL designs on their learning outcomes. Additionally, one UDL expert participant of the present study suggested that open-ended questions asking students to provide specific feedback as to what designs worked for them would provide directions for improvements in UDL-based instructional designs. This opens another potential research area, which is to investigate whether and how adding items in an open-ended response format to the instrument could increase its utility.

Implications for Practice

There is simply no alternative to asking for student feedback or perceptions by assessing their learning experiences with the instructional designs (Greenwald, 1997). As indicated earlier, research has shown that student perceptions of learning environments would affect their learning behaviors and predict learning outcomes (Bell & Aldridge, 2014; Lüdtke et al., 2009). The implication for practice is that educators can use the Sensor to track changes in individual student learning experiences over time and then determine whether the design of UDL-based learning environment meet needs for all learners.

In addition to ensuring reliability and validity, another important factor that influences educators' decision as to whether or not to use student feedback to improve instruction is their openness to the idea of using student perceptions for improvement. Specifically, educators will have to determine how the evidence provided by students could be assessed to estimate whether instructional designs meet their needs in a reliable and valid manner. If teachers feel doubtful about the validity of student feedback in terms of subjective evaluation or perceptions, it is less likely for them to use the feedback for improvement. Previous studies suggest that educators were more likely to support the idea of using student feedback in classroom if they were first asked whether they should provide feedback on principals (Gehlbach et al., 2017). As such, establishing a culture of trust or a mutual feedback system will potentially increase educators' willingness or openness to utilize the Sensor to solicit student perceptions of UDL-based learning environments.

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Learner-Centered Sensor Constructs, Items, and Alignment to UDL Core Credential

Construct	Items Soliciting Student Perceptions of UDL-based Support	Alignment to Core Credential
Clear and Relevant Goals (CRG)	1. I understood the goals of the lesson. 2. I learned useful things in the lesson. 3. The lesson included things that were related to my interests. 4. Things I did in this lesson helped me meet the goals of the lesson.	(CG) The goal is presented so learners can perceive and understand the goal. (RG) The goal is presented to highlight relevance.
Flexible Materials and Methods (FMM)	5. The teacher provided me with choices of content that helped me learn. 6. The teacher provided me with options to show what I know. 7. There were various ways that I was able to participate in the lesson. 8. I was able to choose learning materials (e.g., textbooks, laptop, iPad, guided notes) that helped me learn. 9. I was provided with choices in how I learned during the lesson.	(FMe) The flexible methods are available for learners. (FMa) The flexible materials are available for learners.
Timely Progress Monitoring (TPM)	10. I had multiple **opportunities** to show what I learned during the lesson. 11. There were multiple **ways** I was able to show my understanding during the lesson. 12. When I don't understand during the lesson, my teacher provides me other ways to understand. 13. When I get something wrong, my teacher provides me with feedback on how to improve. 14. I was provided opportunities during the lesson to check my progress along the way. 15. I had opportunities to self-reflect on whether I was meeting the goals of the lesson.	(AS) There are opportunities for flexible assessment options. (SG) The goal is separate from the means, where possible.
Supporting Learner Variability (SLV)	16. How well did you understand the content of the lesson? 17. How engaged were you during the lesson? 18. How challenging was the lesson? 19. How easy was it to identify what needed to get done to meet the lesson goals? 20. How well did the activities during the lesson help you meet the lesson goals?	
Expert learning (optional)	21. I knew what to do if I felt confused during any point of the lesson. 22. I was motivated to achieve the goals of the lesson. 23. What I learned in the lesson helped me solve new problems. 24. I used what I learned in the past to better understand new ideas in the lesson. 25. I was encouraged to solve problems on my own before asking for help. 26. I learned new strategies to help me complete the lesson goals.	(EL) The goal promotes expert learning by encouraging challenging ways of thinking and doing.

Table 4

Expert Ratings on Relevance and Clarity of Each Items ***to Clear and Relevant Goals (CRG)***

Items	E1		E2		E3		E4		E5		E6		E7		Number of Items Rated 3 or 4 for Relevancy	I-CVI (K) for Relevancy	Number of Items Rated 3 or 4 for Clarity	I-CVI (K) for Clarity
	R	C	R	C	R	C	R	C	R	C	R	C	R	C				
1. I understood the goals of the lesson.	4	4	4	4	4	4	4	4	4	4	4	4	4	4	7	1 (1)	7	1 (1)
2. The things I learned in the lesson were helpful to me.	4	3	3	2	4	4	4	3	3	3	4	4	4	4	7	1 (1)	6	0.86 (0.85)
3. The lesson went along with my interests.	3	2	D	D	4	4	4	4	3	3	3	3	4	4	6	0.86 (0.85)	5	0.71 (0.65)
																S-CVI/Ave = 0.95		S-CVI/Ave = 0.86

Note. I-CVI = item-level content validity index; S-CVI/Ave = scale-level content validity index (average); S-CVI/Ave = scale-level content validity index (universal agreement); C = Clarity; D = Delete; R = relevanc

Table 5

Expert Ratings on Relevance and Clarity of Each Items to ***Flexible Instructional Methods and Materials (FMM)***

Items	E1		E2		E3		E4		E5		E6		E7		Number of Items Rated 3 or 4 for Relevancy	I-CVI (K) for Relevancy	Number of Items Rated 3 or 4 for Clarity	I-CVI (K) for Clarity
	R	C	R	C	R	C	R	C	R	C	R	C	R	C				
4. The teacher provided me with options to learn the content during the lesson.	4	4	4	4	4	2	4	4	4	4	4	4	4	4	7	1.00 (1.00)	6	0.86 (0.85)
5. The teacher provided me with options to show what I learned from the lesson.	4	4	4	4	4	3	4	4	4	4	4	4	4	4	7	1.00 (1.00)	7	1.00 (1.00)
6. There were multiple ways that I was able to participate in the lesson.	4	4	4	4	4	3	4	3	4	4	4	4	4	4	7	1.00 (1.00)	7	1.00 (1.00)
7. There were multiple ways I learned during the lesson.	4	3	3	3	4	3	4	3	3	3	4	4	4	4	7	1.00 (1.00)	7	1.00 (1.00)
8. I was provided with choices in materials I used to complete the lesson goals.	4	4	4	2	4	3	4	4	4	4	4	4	4	4	7	1.00 (1.00)	6	0.86 (0.85)
9. I was provided with choices in how I learned during the lesson.	4	4	4	4	4	3	4	4	4	4	4	4	4	4	7	1.00 (1.00)	7	1.00 (1.00)
																S-CVI/Ave = 1.00		S-CVI/Ave = 0.95

Note. I-CVI = item-level content validity index; S-CVI/Ave = scale-level content validity index (average); S-CVI/Ave = scale-level content validity index (universal agreement); C = Clarity; D = Delete; R = relevancy

Table 6

Expert Ratings on Relevance and Clarity of Each Items to ***Timely Progress Monitoring (TPM)***

Items	E1		E2		E3		E4		E5		E6		E7		Number of Items Rated 3 or 4 for Relevancy	I-CVI (K) for Relevancy	Number of Items Rated 3 or 4 for Clarity	I-CVI (K) for Clarity
	R	C	R	C	R	C	R	C	R	C	R	C	R	C				
10. I had multiple **opportunities** to show what I learned during the lesson.	4	4	1	4	4	4	4	4	4	4	4	4	4	4	6	0.86 (0.85)	7	1.00 (1.00)
11. There were multiple **ways** I was able to show my understanding during the lesson.	4	4	1	4	4	4	4	4	4	4	4	4	4	4	6	0.86 (0.85)	7	1.00 (1.00)
12. When I don't understand during the lesson, my teacher provides me ways to understand.	4	2	4	4	4	2	4	4	4	3	4	4	4	4	7	1.00 (1.00)	5	0.71 (0.65)
13. When I get something wrong, my teacher provides me with feedback on how to improve.	4	3	4	4	4	4	4	4	4	4	4	4	4	4	7	1.00 (1.00)	7	1.00 (1.00)
14. I was provided opportunities during the lesson to check my progress along the way.	4	4	4	4	4	4	4	4	4	4	4	4	4	4	7	1.00 (1.00)	7	1.00 (1.00)
																S-CVI/Ave = 0.94		S-CVI/Ave = 0.94

Note. I-CVI = item-level content validity index; S-CVI/Ave = scale-level content validity index (average); S-CVI/Ave = scale-level content validity index (universal agreement); C = Clarity; D = Delete; R = relevancy

Table 7

*Expert Ratings on Relevance and Clarity of Each Items to **Expert Learning (EL)***

Items	E1		E2		E3		E4		E5		E6		E7		Number of Items Rated 3 or 4 for Relevancy	I-CVI (K) for Relevancy	Number of Items Rated 3 or 4 for Clarity	I-CVI (K) for Clarity
	R	C	R	C	R	C	R	C	R	C	R	C	R	C				
15. I knew what to do if I felt frustrated during any point of the lesson.	4	4	4	4	4	3	4	4	4	4	4	4	4	4	7	1.00 (1.00)	7	1.00 (1.00)
16. I was motivated to achieve the lesson goals.	4	4	4	4	4	4	4	4	4	4	4	4	4	4	7	1.00 (1.00)	7	1.00 (1.00)
17. What I learned in the lesson helped me solve new problems.	4	4	2	4	4	4	4	4	4	4	4	4	4	4	6	0.86 (0.85)	7	1.00 (1.00)
18. I used past topics to better understand new ideas in the lesson.	4	4	3	3	4	3	4	3	4	4	4	4	4	4	7	1.00 (1.00)	7	1.00 (1.00)
19. I was encouraged to solve problems on my own before asking for help.	4	4	4	4	4	4	4	4	4	4	4	4	4	4	7	1.00 (1.00)	7	1.00 (1.00)
20. I learned new strategies to help me complete the lesson goals.	4	4	4	4	4	4	4	4	4	4	4	4	4	4	7	1.00 (1.00)	7	1.00 (1.00)
																S-CVI/Ave = 0.98		S-CVI/Ave = 1.00

Note. I-CVI = item-level content validity index; S-CVI/Ave = scale-level content validity index (average); S-CVI/Ave = scale-level content validity index (universal agreement); C = Clarity; D = Delete; R = relevancy

Table 8

Expert Ratings on Relevance and Clarity of Each Items to Supporting Learner Variability (SLV)

Items	E1		E2		E3		E4		E5		E6		E7		Number of Items Rated 3 or 4 for Relevancy	I-CVI (K) for Relevancy	Number of Items Rated 3 or 4 for Clarity	I-CVI (K) for Clarity
	R	C	R	C	R	C	R	C	R	C	R	C	R	C				
21. How well did you understand the content of the lesson?	4	4	4	4	4	4	4	4	4	4	4	2	4	4	7	1.00 (1.00)	6	0.86 (0.85)
22. How engaged were you during the lesson?	4	4	4	4	4	4	4	4	4	4	4	2	4	4	7	1.00 (1.00)	6	0.86 (0.85)
23. How challenging was the lesson to complete?	4	4	4	2	4	4	4	4	3	3	4	4	4	4	7	1.00 (1.00)	6	0.86 (0.85)
24. How easy was it to identify what needed to get done to meet the lesson goals?	4	4	4	2	4	4	4	4	4	4	4	4	4	4	7	1.00 (1.00)	6	0.86 (0.85)
25. How well did the activities during the lesson help you meet the lesson goals?	4	4	4	4	4	4	4	4	4	4	4	4	4	4	7	1.00 (1.00)	7	1.00 (1.00)
																S-CVI/Ave = 1.00		S-CVI/Ave = 0.89

Note. I-CVI = item-level content validity index; S-CVI/Ave = scale-level content validity index (average); S-CVI/Ave = scale-level content validity index (universal agreement); C = Clarity; D = Delete; R = relevance

Figure

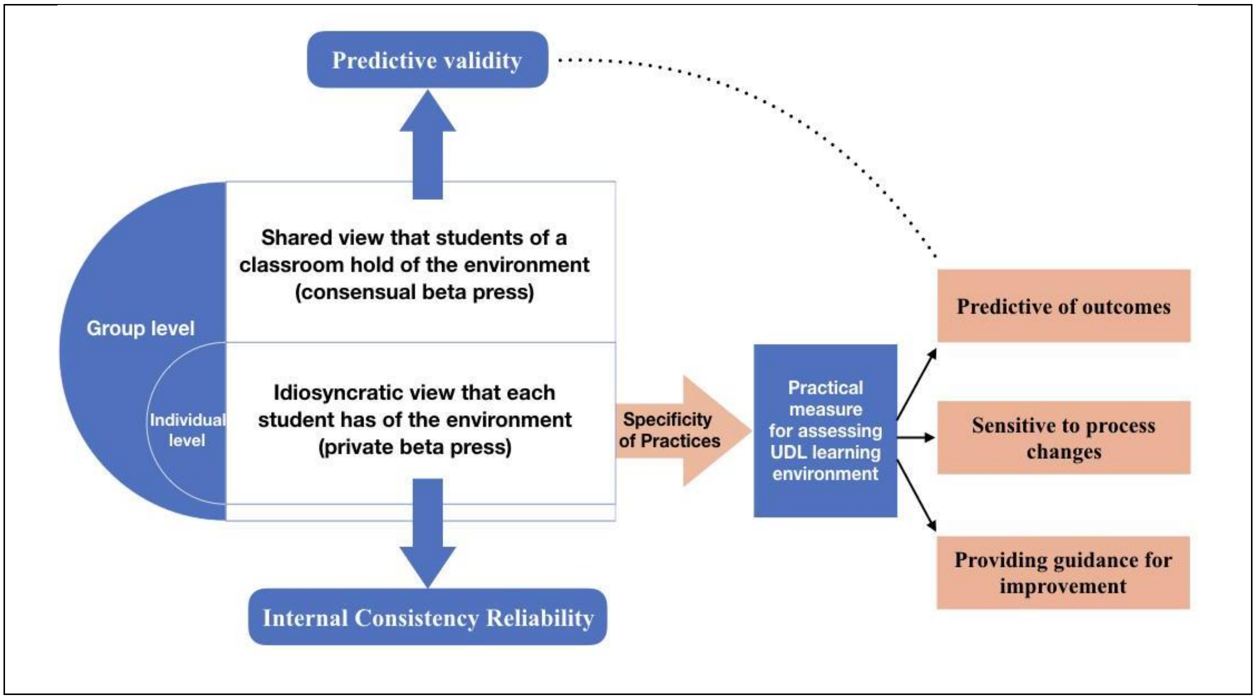

Figure 2. Conceptual framework for developing the Learner-Centered Sensor that combines the merits of both learning environment assessment and practical measurement for instructional improvement; UDL = Universal Design for Learning.

Chapter Five: Discussion, Implication, and Conclusion

As the global education systems are striving to create inclusive and equitable educational opportunities for all learners, more attention will be directed to PL research and practice. Given the growing need to advance a shared understanding of conceptualization and operationalization of PL, this dissertation investigated PL as an emergent, complex educational phenomenon through the lens of UDL. Specifically, this dissertation provided critical information on how to situate the design, implementation, and measurement of PL within the UDL framework. The dissertation contributed to PL research and practice in three aspects: (1) proposed a mechanism that balances learner autonomy and UDL environmental support for establishing PL; (2) provided a comprehensive understanding of how the current PL designs and implementation practices aligned to UDL; and (3) developed a student self-report instrument that could potentially be used to enhance student participation and autonomy in measuring and designing their own PL experiences.

At the policy level, PL has been advocated as a means to transform the traditional “one-size-fits-all” educational model and thus provide equitable educational experiences for all learners, especially for students with disabilities and other students from historically marginalized groups (Chapter One; Chapter Two). On the research side, however, only a few studies have so far investigated the impact of PL strategies, tools, and initiatives on students with disabilities (Chapter Three). The lack of learner diversity in PL research may prevent the field from advancing the innovation to support learning for all learners. When the global education system is challenged to create 21st-century learning environments for all, learner variability needs to be fully embraced and valued in PL policy, research, and practice so that every student can be empowered to reach their maximum potential (Chapter One).

From a practical perspective, PL implementation involves long-term collective efforts from stakeholders in the education system, such as policymakers, researchers, educators, learners, and families. The results of this dissertation provided insight into two main aspects regarding PL practices. First, as discussed in Chapter Two and Chapter Three, the UDL framework has the potential to provide foundational principles and guidance for PL design and implementation. Chapter Two provided a theoretical analysis of UDL's applicability to operationalize PL. Moving beyond theoretical implications, the literature review reported in Chapter Three detailed the alignment, or the lack thereof, between empirical PL implementation practices and the UDL framework. The alignment analysis provided insights and foundational considerations for future efforts in creating UDL-based PL for all learners.

Second, as discussed in Chapter Two and Four, it is critical to creating an avenue for students to self-evaluate their learning experiences, which should be viewed as a key component of PL implementation and measurement. Chapter Two discussed how UDL and self-determination theory converge to address the increased requirement for promoting student autonomy and agency in PL environments. Inspired by self-determination theory, which is one of theoretical foundations for UDL, Chapter Two highlighted the importance of empowering individual learners to self-evaluate learning experience in PL environments. One implication for future research is to investigate how the convergency between UDL and self-determination within a PL context positively, or negatively, impacts student learning. To support such inquiries, Chapter Four proceeded to elaborate on why and how learners' evaluations of learning experience could inform iterative designs of UDL-based learning environments. Furthermore, Chapter Four reported on an initial effort to develop the Learner-Centered Sensor designed to measure student learning experience in a UDL-based PL environment. Results of the validation study in Chapter Four suggested that the Sensor possesses an average excellent level of content validity across its constructs and items for clarify and relevancy. Research is needed to evaluate psychometric properties of the instrument.

To sum, the analysis and results of Chapter Two, Three, and Four suggested a need for establishing a balance between educator UDL implementation and learner autonomy within a PL environment. Additionally, these chapters provided specific implications for future research and practice regarding different aspects of PL supported through UDL. Chapter Five furthers the discussion, with a focus on providing implications for future PL research and practice considering the current circumstances facing the global education system.

Implications for Future PL Research and Practice

In this rapidly-evolving society, the education system is faced with unpredictable changes and disruptions in various forms; however, creating an equitable learning environment that benefits all learners remains to be an unchangeable goal. The most recent and alarming example is the outbreak of the COVID-19 pandemic this year, which has created an unprecedented disruption to the global education systems (UNESCO, 2020). When brick-and-mortar schools are closed during the pandemic, educators around the globe face various challenges of maintaining instruction online, let alone providing equitable and engaging learning experiences for all students. Ironically, the current crisis is acting as a catalyst for transforming and redefining student learning experiences. Its impact on immediate student learning outcomes or long-term educational outcomes is unknown. Yet, it is certain that most student learning experiences have changed, either positively, negatively, or in both ways, as a result of the sudden shift of learning environments from brick-and-mortar to online.

A wide array of factors would contribute to increased positive learning experiences, and the factors vary across learning contexts. Whether educators have capacity to support students in successfully navigating through changing environments and engaging in learning activities is one critical factor. The global COVID-19 crisis has burdened educators, and families in the current circumstances, with sudden disruptions to school routines and high demands for using technology to support student learning. Unfortunately, not all educators or families were prepared; most likely, many are facing a steep learning curve to provide positive online learning experiences for learners. To prepare for the future, the crisis should (if has not yet) evoke reflection on how the educational system should better prepare educators and students for teaching and learning in the 21st-century characterized by unpredictable societal events. One primary question that has been discussed throughout this dissertation, yet requires ongoing conversation and investigation is how learners could benefit from increased PL experiences to thrive in rapidly-changing learning environments. Here, learners refer to both educators and students.

Educators Learn Alongside Students

In the face of substantial changes to where and how to teach, educators who are also learners of new experiences need support for implementing effective instructional practices that lead to positive PL experiences for students. On the positive side, the unexpected disruption could turn into an authentic learning opportunity for all educators to explore factors such as flexible online instructional designs to engage and empower student learning. As a community, educators around the global, nation, or region are learning to overcome obstacles to effective technology-based learning for students. As individuals, educators may face varying challenges and opportunities in terms of improving students' PL experience in their unique context.

Questions remain as to what challenges facing the current practices for teacher preparation and professional development programs. For example, how can educators be better prepared for teaching in evolving learning environments? What structure can be put in place to support both educators and students in engaging in PL experiences? Previous research has shown that how educators have been educated and trained were not effective in meeting their individual professional learning needs, thereby not effective in supporting them to adapt instruction to meet students' diverse needs (Parsons et al., 2017; Yurtseven Avci et al., 2019). For example, there is a consensus that professional learning through practicing within educators' specific contexts, collaboration, and reflection is effective in improving instructional practices and student learning (Darling-Hammond et al., 2017; Garet et al., 2001). However, these components are usually absent from traditional teacher preparation and professional development programs (Darling-Hammond et al., 2017; Desimone, 2009). Research shows that many programs are standardized in delivery format and content, separated from engagement with authentic experiences, and proven ineffective in connecting to individual educators' specific learning needs and contexts (Desimone, 2009; Webster-Wright, 2017).

These challenges loom large for educators to teach in evolving, complex learning environments. Educators should be expected to develop complex problem solving, collaboration, and self-reflection skills for which they hope to prepare their students (Darling-Hammond & Richardson, 2009). To address these challenges, researchers posit that educators benefit from engaging in personalized, self-directed learning and development, which could be transferred into effective instructional practices that yield positive changes in student learning experiences (Yurtseven Avci et al., 2019). It is likely that thinking through the eyes of a learner with individual learning needs would help educators sympathize with their students and potentially design PL experiences for them. Thus, professional learning and development programs need to transition to educator-centered model that develops educators' identities as lifelong learners, adaptive problem solvers, and learning experience designers (U.S. Department of Education, 2017). Nevertheless, research is needed to investigate the effective ways of engaging educators in personalized professional learning and their impact on students' PL experiences.

Students Co-design Learning Experiences

Supported by the research from the learning sciences, designing authentic, engaging tasks with real-world connections to motivate student effort and engagement, is integral to PL operationalization (Walkington & Bernacki, 2015). In a traditional brick-and-mortar environment, these design components of PL can be achieved by teacher scaffolding and various tools that allow for autonomy, student agency, and authentic learning experiences (Darling-Hammond et al., 2019). In a blended or online learning environment when no immediate educator support is present, students need skills such as self-regulation, self-determination, and digital literacy to engage in and take control of their digital PL experiences. As indicated above, student autonomy and control over where, when, and how to learn has been regarded as an essential component of PL (Patrick et al., 2013). Accordingly, there is a growing need for providing an avenue for students to voice their learning needs and develop capacity to assess whether their learning experiences are supported in flexible learning environments.

Implications for Future Research on Measuring Student PL Experience

This dissertation highlighted a need for supporting students to thrive in PL environments. One support is to engage students in self-evaluating learning experiences as a means of calibrating whether the design of learning environment meets their needs. Empowering students to self-reflect on learning experiences is in line with the emphasis of creating autonomy-supportive learning environments as situated within UDL design considerations and self-determination theory. Moreover, using valid and reliable student self-ratings of learning experiences will help gauge whether the designs of PL environment meet individual students' learning needs.

Focusing on Variations in Learning Experiences

As discussed in Chapter Three, student perceptions of a learning environment consist of group-level perceptions that students shared about the environment (e.g., learning platform, classroom, school) and distinct perceptions that individual students have about the environment (den Brok et al., 2006). Differences in individual-level ratings of learning experiences, albeit interesting, might not be reliable in reflecting the overall quality of learning environment design (Wagner et al., 2013). Yet, those differences captured by validated measurements represent unique experiences of each student that are not explained by the shared perceptions of their learning experience (Morin et al., 2014). These differences are often overlooked in previous studies on learning environment assessments (den Brok et al., 2006), but are of vital importance for UDL-based learning environment given that attending to individual learning needs is at the core of UDL implementation.

In terms of the *Sensor*, the tool was designed to capture different UDL-aligned learning environment characteristics across contexts based on group-level student perception data aggregated from individual students' perception data that account for agreement among students within the same class. With further validation on its psychometric properties, the *Sensor* has the potential to collect data to inform practical instructional improvement if differences in individual-level ratings of learning experiences supported or impeded by learning environment designs are identified. One important research avenue is to investigate the practical ways the

Sensor is used to gather data on real-time individual learning experiences, and then signal malleable factors to which changes might be introduced to address variation among individual learning needs.

Timely Assessing Learning Experiences

Administration of the *Sensor* at multiple time points could provide an index of the extent to which instructional activities (un)change over time, which in turn could be correlated with students' educational outcomes. Usually, single source of data collection and use at a fixed time point is likely to give rise to bias in interpretation and evaluation of educational innovations or programs. Thus, longitudinal studies and growth analytical models are needed to test the predictive validity of the *Sensor*. To address these issues, future research could consider using real-time data and repeated measurements, coupled with advanced analytic approaches, to track individual students' learning progress. For example, latent growth curve models can be used to help distinguish between-student from within-student relationships among variables and allow for trajectories to vary between individuals over time (Hoffman, 2015). Experience sampling method (ESM) is another widely used approach to investigating and examining real-time experiences (Hektner et al., 2007). ESM is often used to ask individuals to respond to randomly emitted signals in real time, thereby producing ecologically valid responses (Courvoisier et al., 2012).

Conclusion

The current disruption to the global education system that technology provides challenges and solutions to teaching and learning. To promote inclusive and equality education, a more accurate interpretation of learning variability inherent in all learners to help establish a mindset among stakeholders that all students should be educated and challenged to reach their maximum potentials. This mindset should urge stakeholders to focus on creating PL environments for all students based on their needs, interests, and preferences. To make systemic changes in educational systems by personalizing student learning specify that the implementation can be anchored on UDL and supported by robust technology and data infrastructure.

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