Appraising Research on Personalized Learning: Definitions, Theoretical Alignment, Advancements, and Future Directions

Candace Walkington, Southern Methodist University, cwalkington@smu.edu
Matthew Bernacki, University of North Carolina – Chapel Hill, mlb@unc.edu

1. Introduction

The nature of formal and informal education is rapidly evolving; learners are coming to expect a high level of customization, interaction, and control when seeking knowledge (Collins & Halverson, 2009; Papert, 1980, 1983). Both "personalization" and "personalized learning" (PL) are increasingly used as buzz words in educational contexts, but little consensus exists about their respective definitions. The National Academy of Engineering named the development of personalized learning systems a "Grand Challenge" for the 21st century (Ellis, 2008) alongside initiatives like understanding the nitrogen cycle and reverse-engineering the brain. These grand challenges were selected to be transformative on a global scale.

Outside of educational fields, personalization has been widely popularized as a method of allowing customers to experience services that are adapted to suit their needs through mechanisms like recommender systems, smart ads, customizable interfaces and avatars, and promotional merchandise. However, some have noted problems that arise when corporate examples of customization (e.g., Pandora, Amazon) serve as a base for PL, and argue that this kind of surface-level adaptation to learners' needs gives the illusion of control to the learner rather than deeply reflecting their interests and goals (Wilson, 2014). In the context of these diverging viewpoints, the ways personalization has been applied to education have been widely variable, and solidifying an evidence base to evaluate PL approaches has been problematic (Beese, 2019; Cuban, 2018; Enyedy, 2014; Halverson, 2019).

This special issue includes nine articles that conceptualize how PL can be designed, document how it is being implemented, and report the outcomes of PL initiatives. The purpose of this introductory article is to analyze the conceptualizations of PL in these articles, to highlight areas of synergy, and appraise areas of progress and stumbling blocks en route to a science of PL. To organize our collective thinking about ways PL might most productively accommodate learners and promote better learning, we also consider how theories of learning can inform PL design and implementation, and identify overarching, persistent issues that face the field of PL. We close by giving directions for future work.

The first pair of articles in this special issue are a paper giving an analysis of the state-level policies that govern PL initiatives across the United States, and a conceptual paper that considers the design of learning for adaptivity and PL. Carter (this issue) explores how states in the U.S. have defined PL in response to the 2015 Every Student Succeeds Act (ESSA), and what this tells us about the kinds of implementations that may be happening in schools. Plass (this issue) details a taxonomy for "adaptive learning," which specifies the learner variables systems could adapt to, how those variables can be measured, and what kinds of adaptations can be made in response to these learner variables. The following two articles explore PL in online or blended learning

systems. McCarthy et al. (this issue) describe a quantitative research study involving an experiment where the iSTART computer-based tutoring system for reading implemented adaptive logic to adjust text difficulty based on student performance. Alamri and Lowell (this issue) present a qualitative study of the effects of redeveloping online graduate coursework to personalize learning to students' career goals and implementing choice of interest-based materials, progressions, and assignments.

These articles are followed by three that conceptualize PL as an approach to school reform at scale – McCarthy and Liu (this issue) report on a quantitative study examining learning outcomes of a district PL initiative in public K-5 schools, while Kallio et al. (this issue) and McHugh et al. (this issue) examine the Personalization in Practice (PiP) initiative in public schools in the Midwest. Kallio et al. take a qualitative approach to examine important leadership structures for PL, while McHugh et al. engage in text analysis of teachers' and students' conceptions of PL from interviews. The final two articles in the special issue examine instructional interventions driven by students' interests. Garrett et al. (this issue) conduct a mixed methods study on an intervention for College Algebra where students analyze real datasets related to their interests. Finally, Tsybulsky (this issue) reports a qualitative study of high school students engaged in interest-driven digital curation activities. The key features of the seven empirical articles in the special issue are summarized in Table 1, and all nine articles are further discussed in the following sections.

When recruiting, inviting, and editing the manuscripts that appear in this special issue, we made a series of conscious decisions to prioritize exemplars of PL research that demonstrate how the design of PL can proceed according to learning theory, as well as studies of implementations that explore how learning theory and research can inform practice. All papers had to make evident the prominent role that theories of learning played in the design and appraisal of PL in their studies, and to make clear how such learning theory can inform a focus on learner characteristics and learning outcomes, and how one designs or implements PL. These considerations are made visible in Table 1.

2. Definitions of Personalized Learning

How Personalized Learning is defined

The U.S. Department of Education (2010, 2016) defines personalized learning as "instruction in which the pace of learning and the instructional approach are optimized for the needs of each learner. Learning objectives, instructional approaches, and instructional content (and its sequencing) all may vary based on learner needs. In addition, learning activities are meaningful and relevant to learners, driven by their interests, and often self-initiated" (2016, p. 7). The U.S. Department of Education's (2010) definition further clarifies that *individualization* involves pacing instruction according to learning needs and *differentiation* involves tailoring to learning preferences by changing the method or approach of instruction. Thus, in order for instruction to truly involve PL according to this definition, the third sentence of the above definition (i.e., meaningfulness, relevance, interest-driven, self-initiated), is the key consideration. This overarching definition conforms to research on PL in educational psychology, which explores

Table 1

Key characteristics of 7 empirical articles in PL Special Issue

Lead Author	[Implicit] Theoretical Frameworks	Study Context (platform; domain; learner)	Learner Characteristic (to which learning is personalized)	Method of Personalizing Learning	Intended Outcome	Results
Alamri	Self-Determination; Social Constructivism; Interest;	Online course; Professional development for educators; adult learners	Students' "needs, interests, and preferences" (inferred to inform observable choices)	Student choice of Learning pathways, assignment design features; personalized instructor feedback;	Psychological need satisfaction; self-perception of learning	Qualitative reports of more increase in interest, satisfaction of goals; Feelings of relatedness mixed;
Garrett	[Situational Interest] Connectivism	MS Excel, data from websites; Algebra; Undergraduates	Personal interests	Embedding math tasks in student-chosen contexts	Mathematical understanding (of functions)	Effect size of difference on pre to post gains; Average = .16 (range .30 to -.22)
Kallio	Distributed leadership; Project-based Learning; Competency-based Assessment	3 years of Documents from 12 schools; administrators	"student's interests, agency, and learning relationships"	Redesign of learning environment, including adopting and connecting technologies, adjusting use of instructional time	Identified leadership tasks to facilitate PL	Physical and temporal features of learning and technology affordances require revision
McCarthy (Blended Learning)	Strengths-based learning; blended learning; Social constructivism;	District-wide, Math, Reading, Language; K-12 students	Prior performance (in digital curricula); student choice (in classroom); students goals (negotiated with teachers); students' strengths (assessed)	Competency-based progressions; flexible learning environments; personal paths; student profiles; frequent informal & formal assessment	Math, Reading, and Language achievement	Positive, significant but small effects ($d \sim 0.1$) on all three subjects
McCarthy (iSTART)	Self-explanation principle, metacognitive comprehension monitoring	iSTART; reading; high school students	Prior reading performance (informs text selection); self-explanation content (informs feedback)	Adaptive text selection; just-in-time support (formative feedback based on NLP-identified self-explanation features); game mechanics (points for explanation quality, leveling up, unlock affordances, personal avatars)	Self-reported learning, reading comprehension, engagement, reported motivation and enjoyment	Increased self-reported learning; Pre-post gains in comprehension, larger for less-skilled readers
McHugh	(Socially-shared) self-regulated learning	Interview transcripts spanning multiple	Emergent, based on students' interests and strengths	Emergent, based on implementation of state PL initiative; adopted tools included	Not stated.	Little overlap in student and teacher discussion of PL; common phrases

		subjects with practicing teachers and their students		IXL and Acellus software that provide adaptive math and language learning, support for independent study, respectively		limited to “IXL,” “Artifact,” and “Freshman”
Tsybulsky	Epistemic cognition, metacognitive thinking	Google sites; science; 9-12 grade students	Individual interests	Learned control choice of topic, content to curate	Cognitive processing; emotional experiences	Qualitative reports of learning, satisfaction achieved by choice; positive and negative emotions during curation, annotation

the effect of interest-based connections on motivation and learning (e.g., Bernacki & Walkington, 2018; Cordova & Lepper, 1996; Walkington, 2013; Reber et al., 2009), utility value interventions (e.g., Hulleman et al., 2010), and instructional approaches involving student agency or choice (e.g., Patall, 2013).

A related definition of PL that has been particularly influential in schools is that of Bray and McClaskey (2015) in their book *Making Learning Personal*: "In a personalized learning environment, learners actively participate in their learning. They have a voice in what they are learning based on how they learn best. Learners have a choice in how they demonstrate what they know and provide evidence of their learning. In a learner-centered environment, learners own and co-design their learning. The teacher is their guide on their personal journey" (p. 14). This definition shares many characteristics with the DOE definition, and explicitly positions the student in a role of ownership, choice, and control. But not all definitions of PL have this emphasis. Eduvate Rhode Island (2017) reviewed a variety of definitions of PL, and identified 8 common themes: individualization, differentiation, standards-aligned, student owned, socially embedded, connected to student interests, in flexible environments, and enacted with continuous formative assessment. PL in practice could be viewed as varied collections that involve some or all of these elements.

Accordingly, Cuban (2018) proposes viewing PL approaches on a continuum, rather than staking out a single static definition. He proposes that one side of the continuum includes teacher-centered lessons using learning technologies (including teacher-crafted playlists) that convey standards-based skills and that are tailored to individual student performance. The other side of the continuum is student-centered classrooms, which can integrate across subject areas and which can incorporate community-based activities, where students shape learning opportunities based on their interests and passions, utilizing new technologies. Both sides of this continuum would fall into the "big tent" definition of PL recently proposed by Beese (2019): "Educational personalization is best conceived, broadly, as that which occurs in any process that uses information from or about a student to generate educational plans or decisions for that student" (p. 254). This definition of PL is intended to bring many different research traditions under one umbrella, to encourage researchers to integrate their understanding of PL's affordances and constraints among different traditions and approaches (e.g., student tracking as PL), and to enhance collaboration between researchers engaging in the design and evaluation of PL.

We (Walkington & Bernacki, 2014) have also contributed to this discussion by describing how different approaches to PL can vary on three dimensions that are relevant to theories of learning. First, PL can occur at variable degrees of *depth*, which captures the extent to which instructional tasks and the instructional environment take into account the lived, authentic experiences of learners. For example, learning can be personalized to a student's characteristics at a very surface level (e.g., including the student's name or favorite food in a problem task to elicit attention) or at a level that connects to meaningful learner characteristics (e.g., a course centered around a learner's career trajectory – see Alamri and Lowell, this issue) or incorporates learner interests in ways that authentically connect to the content to be learned (e.g., having students mathematically model personally relevant data in Garrett et al., this issue, or having students digitally curate an interest-based collection in Tsybulsky, this issue).

Second, PL can occur at different *grain sizes* where the experience is personalized for each learner individually, for small groups of learners matched on specific dimensions, or larger groups based on more general parameters. For example, adjusting a learning task to known characteristics of a population of students (e.g., geographic area, reading level) could be seen as broad grain size personalization. Medium grain size personalization could adapt to smaller groups of students – like the course Alamri and Lowell (this issue) describe where students complete activities in the context of four career pathways. And small grain size personalization can give each individual student a different learning experience – often through adaptive technology systems (McCarthy et al., this issue; Plass, this issue), or by leveraging student expertise and individual interests (Garrett et al., this issue, Tsybulsky, this issue).

And finally, PL can vary with respect to *ownership* – the degree to which learners are given control and choice in the learning situation. Some designs do not allow for student choice as they implement automatic adaptivity driven by a technology system (McCarthy et al., this issue), while others explicitly take into account students' autonomy and agency (McHugh et al., this issue; Kallio et al., this issue), while still others allow learners to be the drivers of instruction and even select the content they want to learn about (Tsybulsky, this issue). While these three dimensions are not an exhaustive list of ways PL approaches may differ, these dimensions and others may be important for understanding and reconciling different PL research results. This theory of PL (Walkington & Bernacki, 2014) focuses on the ways that a learning environment can be altered to benefit students' cognitive, motivational, and affective processes that influence their learning. As a result, the theory describes some design features of PL quite well and in ways that allow systematic analysis of their implications (e.g. Bernacki & Walkington, 2018).

How Personalized Learning is defined in the special issue articles

We divide the articles in the special issue into four categories in terms of their definitions of PL, and organized the issue accordingly – and note there would certainly be other ways to divide them. One article in the special issue defines PL in an emergent manner, by looking at how states in their sample define PL. Carter (this issue) describes how the wording of ESSA suggests that PL involves "high-quality academic tutoring" and is "an instructional practice supported by the effective use of data and information to strengthen students' digital learning experiences" (p. ##). Through an analysis of state documents, he shows how definitions of PL among states who are operationalizing the guidance in ESSA vary widely. All of the definitions relate in some manner to tailoring learning to individual learners, while other themes include a well-rounded education, a focus on marginalized groups, alternative pathways, school-wide improvement, technology, universal design of learning, learner profiles, individualized learning paths, competency-based progressions, flexible learning environments, and blended learning. Carter provides a complete, emergent definition of PL based on the varied state policy documents at the end of the article:

> Personalized learning is a systematic learning design which focuses on tailoring instruction to individual students' strengths, preferences, needs, and goals that leads to well-rounded educational experiences including increased access to disciplines and 21st-century work skills. Personalized learning provides flexibility and supports in what, how, when, and where students learn and demonstrate mastery of learning. Specifically, these flexibilities and supports are designed in instructional approaches, content, activities,

> learning objectives and outcomes, pace of learning, and alternative pathways toward college and career. In addition, personalized learning enables student voice and choice based upon their interest, prior learning, and affords students opportunities to influence their learning path. Personalized learning systems often leverage technology to enhance access to quality learning experiences for all learners, support educators in effective implementation practices, and strengthen school-level technological infrastructure (e.g., digital platform, online data system). (p. ##)

Three additional articles in the special issue focus on PL as it is enacted in computer adaptive or blended learning technology platforms. Plass (this issue) focuses on adaptivity rather than PL, defining it as "the ability of a learning system to diagnose a range of learner variables, and to accommodate a learners' specific needs by making appropriate adjustments to the learner's experience with the goal of enhancing learning outcomes" (p. ##). McCarthy et al. (this issue) define PL as "tailored to an individual learner's strengths, interests, and needs," accentuating that PL is self-initiated, student-centered, and involves personal relevance (although these three characteristics are not the focus of their study). Alamri and Lowell (this issue) define PL as "a learner-centered instructional approach… that can be implemented to provide instructional content focused on addressing learner needs and interests" (p. ##), and describe how PL principles include "personalized instructional goals, personalized instruction focused on learners' interests, personal learning choices, and learner control" (p. ##).

Three articles take a whole-school reform approach to their definition of PL, incorporating many aspects of the school system into the changes that result in student learning becoming personalized. McCarthy and Liu (this issue) define PL as encompassing competency-based progressions, flexible learning environments, personal learning paths, frequent formal and informal measurement, and student profiles. They also add on an element of strengths-based learning, which involves students reflecting and setting goals with teachers, measuring their strengths using assessments, choosing learning activities related to their strengths, and receiving affirmation related to strengths. Kallio et al. (this issue) define PL as "a collection of practices designed to place student interests and needs at the heart of schooling. These practices include efforts to redesign teaching, learning and assessment in order to create learning plans that lead each student toward competency-based assessments" (p. ##). They also highlight four specific PL-related practices: "personalized learning plans, project-based learning, competency-based assessments, and integrating data-driven learning technologies" (p. ##). McHugh et al. (this issue) define PL as a "pedagogical strategy, or a general instructional design or method used to deliver content and activities to students (e.g., integrating computers into overall curriculum delivery in an effort to increase computer literacy and student autonomy), that values student autonomy and agency to improve learning outcomes" (p. ##).

The two final articles in the special issue define PL as instruction where learners have control over the specific academic content they are learning, such that it can become aligned to their interests. Garrett et al. (this issue) define PL by stating "Mathematics instruction is personalized when the mathematical content is connected to students' personal interests and lives" (p. ##). Tsybulsky (this issue) defines PL as learners "making decisions that are guided by personal interests and preferences, abilities, and prior knowledge" (p. ##).

3. Theories of Learning Undergirding Personalized Learning

Theories of learning generally assume that learners' characteristics influence the ways that they engage in learning environments, and the outcomes that are obtained (Figure 1; above broken line). Theories of PL and adaptivity propose that information about a learner, derived from data that is available or choices they make, can be used to adapt features of the learning environment to enhance learning outcomes (Figure 1; below broken line). A key observation from Figure 1 is that *PL is not itself a theory of learning*. Rather, we see PL as an overarching method to leverage existing learning theories, in conjunction with educators' practical experience and learners' input, to modify aspects of a learning environment to meet learner needs.

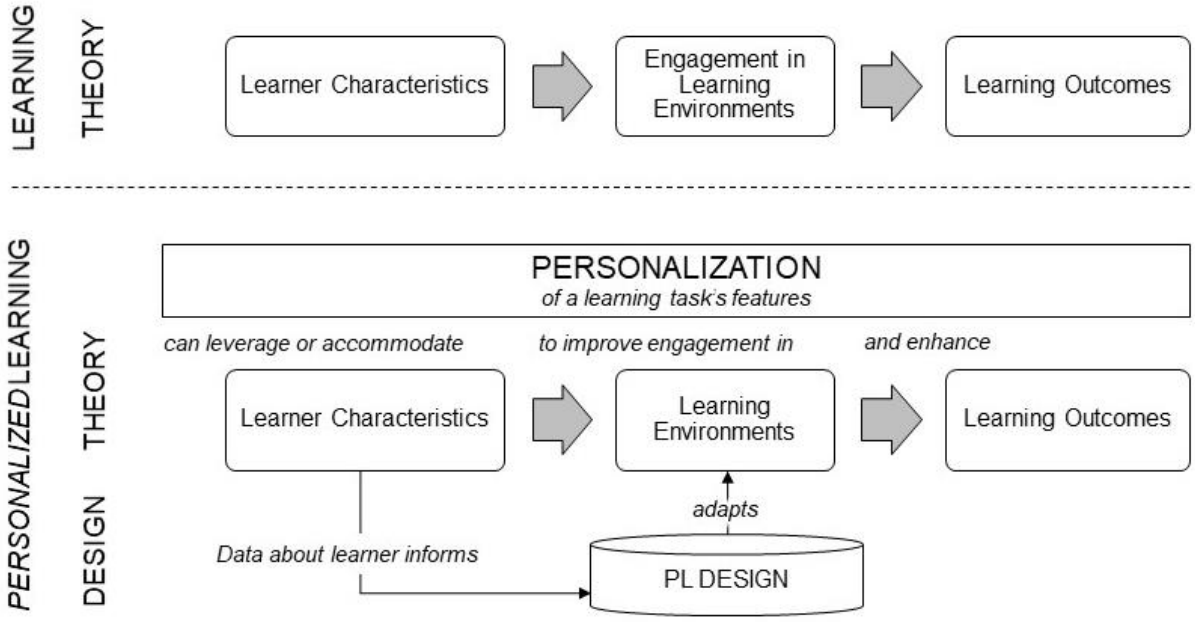

Figure 1. General model of assumptions of learning theories, and the augmentation of learning through personalization of a learning environment to individual learners.

Personalizing learning tasks and classroom and school environments

In Figure 1, PL design leads to changes in the learning environment, broadly construed. The full scope of efforts that define the PL initiatives typically incorporate multiple activities. These might include some combination of PL in *instructional tasks* that leverage learner characteristics to adapt instruction (e.g., software that paces instruction based on performance; c.f. Plass, this issue). Other efforts might focus on *classroom PL implementations* to afford students the opportunity to choose and direct their own learning, often along "learning pathways" that align to their personal goals and interests. Broader implementations may span classrooms as *institutional PL initiatives*, where educators work with students to provide a PL experience that spans across academic subjects and other spheres of school life (Bernacki, Greene, & Lobczowski, working paper).

This special issue contains examples of PL environments that span task, classroom, and institutional levels. Garrett (this issue) demonstrates how instructors can invite students to personalize math tasks by selecting personally-relevant data. Tsybulsky (this issue) provides a second example where within a science learning task, students curated a collection of artifacts that collectively represented their engagement with media. McCarthy et al. (this issue) demonstrate how reading comprehension tasks can be personalized. Other author groups provide examples of the way classroom-level implementations can combine multiple methods to personalize learning. Alamri et al. (this issue) redesigned an online course to provide students with ownership and autonomy in their learning experience. Teachers and students who completed interviews in McHugh et al. (this issue) report on the elements of the classroom that provided a PL experience. At the institutional level, Kallio et al. (this issue) document how administrative leaders reported their respective PL efforts in their schools, and McCarthy and Liu (this issue) report on a district-wide blended learning initiative based on PL design choices.

These PL efforts demonstrate a continuum that spans tightly controlled-experimental designs varying a single PL factor, to making many changes to a learning environment and studying the effects. The implementation of multiple PL design elements together can maximize the potential benefit to learners, although it does not allow for factors to be isolated. Whereas the projects in the special issue include both theory-advancing and applied aims, each is conceptualized according to one or more educational theories that guided the design and appraisal of PL efforts.

Learning theories in the special issue articles

A variety of learning theories have been used to motivate and undergird PL interventions. These include theories such as mastery learning (Bloom, 1968), differentiation (Tomlinson, 2000), self-determination theory (Deci & Ryan, 2002), interest theory (Hidi & Renninger, 2006), funds of knowledge (Moll, Amanti, Neff, & Gonzalez, 1992), and situated cognition (Lave & Wenger, 1992), among many others. As can be seen in the second column of Table 1, the number of learning theories that are relevant to PL in this special issue alone are many – from self-determination theory (Alamri & Lowell, this issue), to connectivism (Garrett et al., this issue), to strengths-based learning (McCarthy & Liu, this issue), to self-regulated learning (McHugh et al., this issue), to distributed leadership (Kallio et al., this issue) to metacognitive thinking (Tsybulsky, this issue).

Multiple theoretical traditions can be used simultaneously in individual studies. For example, much of our work on PL has demonstrated that simultaneously leveraging theories of interest development (Hidi & Renninger, 2006) and funds of knowledge (Moll et al., 1992) is essential to understanding how PL achieves effects on math performance and interest. When learning theories are considered in fine detail and design choices are substantiated at the level of specific theoretical assumptions, clearer design choices can be made, and prior evidence allows designers to have more confidence that their efforts will lead to their desired outcomes.

For example, a number of papers in this special issue described PL methods that involved providing students with choices. This design is derived from multiple learning theories. Choice is

known to enhance intrinsic motivation, effort, task performance, and perceived competence, among other outcomes (Patall, Cooper & Robinson, 2008), but can also diminish learning when students are provided choices and choose not to challenge themselves (Long & Aleven, 2013). Alamri and Lowell (this issue) provided choice to students, under the assumption of self-determination theorists (Deci & Ryan, 2000) that choice might promote greater perceptions of autonomy. McCarthy and Liu (this issue) examine a blended learning model which also incorporates student choice. Other PL efforts gave students choices under the assumption that choice would allow opportunities to self-regulate learning. McHugh et al. (this issue), frame their PL study through the lens of socially-shared regulation of learning (Hadwin et al., 2011), a theory that derives out of the social cognitive tradition and involves cognitive, metacognitive, and social processes, along with motivational processes. Garrett et al.'s (this issue) intervention gives students choice in the kinds of data they incorporated into a learning task, and in a way, achieved a form of context personalization (Walkington & Bernacki, 2014) known to promote greater situational interest (Bernacki & Walkington, 2018). Most of these studies achieve some effects on student perceptions or student learning.

The enthusiasm for PL and adoption of complex approaches to PL that are prevalent across the U.S. (Carter, this issue) and in specific districts that are leaders in PL implementation (Kallio et al., this issue; McCarthy & Liu, this issue; McHugh et al., this issue) confirm that additional efforts will be needed to evaluate PL endeavors holistically, as they are implemented in authentic educational environments. In the next section, we discuss the research results of the PL articles in this special issue.

4. Research on Personalized Learning

In the U.S., two of the most well-known studies on the impact of PL at scale were conducted on samples of schools who received funding from the Bill and Melinda Gates Foundation (Pane et al., 2015; RAND Corporation, 2014). The resulting reports suggest an impact of PL on achievement in math and reading at public charter schools. The later report also found that across the PL schools, flexibly grouping students for instruction, sharing and discussing achievement data with students, and having a physical space organized effectively for PL, were important in predicting growth across school types. But this kind of large-scale evaluation of a PL model is rare. Results for "blended learning" models more generally (i.e., instructional approaches combining online and face-to-face activities) have shown modest positive effects (Means, Toyama, Murphy, & Baki, 2013). However, results are variable; for example, in K-12 mathematics, evaluations of blended learning platforms have shown some positive results for Khan Academy (Murphy, Gallagher, Krumm, Mislevy, & Hafter, 2014), Cognitive Tutor Algebra (Pane, McCaffrey, & Karam, 2014), and ASSISTments (Roschelle, Feng, Murphy, & Mason, 2016), and more recent null results for Teach to One: Math (Ready, Conn, Bretas, & Daruwala, 2019) and Reasoning Mind (Shechtman, Roschelle, Feng, & Singleton, 2019).

The articles in this special issue make progress on building an evidence base for effective practices for PL. In the following section, we discuss how the special issue articles (1) demonstrate or do not demonstrate evidence of effectiveness for approaches to PL, (2) reveal

conditions for successful implementation of PL, (3) include considerations related to scale-up of PL.

Summary of results of special issue articles

When reporting results from articles in the special issue, we first report three empirical pieces that employed a quantitative design with a comparison group to study the impact of a particular approach to PL. We then report on one qualitative study of school leaders' experience and two qualitative studies of students' experience with PL courses to further reveal further evidence of PL's effectiveness and conditions of successful implementation. We then discuss the special issue articles that have implications for implementing PL at scale.

McCarthy and Liu (this issue) directly build upon the evidence base established by the two aforementioned reports from the Gates Foundation initiative. Their article examines the standardized math, reading, and language test scores of K-5 students in a district utilizing PL at scale, and considers their performance against a virtual control group (i.e., where PL is not in place). The study found that over a 3-year period, the 1911 students in the treatment group significantly outperformed their peers from the virtual comparison group on the MAP assessments, with effect sizes (Hedge's *g*) ranging from 0.10 (language usage) to 0.12 (mathematics and reading). In another special issue article, using the established iSTART platform, McCarthy et al. (this issue) conducted a comparative quantitative analysis examining the ways personalization of reading tasks influences learning outcomes. Their study examined adaptive selection of the difficulty of texts based on prior student performance and analyses indicated that high school learners who received adaptive text selection achieved greater comprehension test gains compared to students receiving random text selection, but only if they were less-skilled readers. They found no significant overall differences in performance, and no differences in self-reported motivation or engagement.

Garrett et al. (this issue) conducted a mixed-methods study that examined the impact of enabling students to select personally-meaningful datasets for assignments in a College Algebra course. They found no significant differences on learning measures when students could select personalized datasets versus being assigned non-personalized datasets, but their study design may not have provided sufficient statistical power to detect smaller effects. They also did not collect additional data on students' interest in the math task or measures of engagement (e.g., Bernacki & Walkington, 2018, Høgheim & Reber, 2015). In line with these prior studies, their qualitative data suggests that students were able to make personal connections to the assignments, and in some cases demonstrated emotional investment. Kallio et al. (this issue) conducted a qualitative study examining how educational leaders implement PL, and found three tasks that, when leaders undertake them, might support successful implementation: redesigning physical spaces to support teacher and learner agency, assembling tools to create a technology ecosystem, and redesigning instructional time to support conferring with students.

Alamri and Lowell (this issue) conducted a qualitative study of the implications of the redesign of an online graduate course through the lens of self-determination theory. The redesign included

providing students choice between four career-focused pathways, timing and type of assessments and personal learning goals. Students' reflections on their learning suggested that students found the PL course more relevant and aligned to their goals, and that is was more successful at enhancing their perceived interest and engagement. However, students also reported that they did not have a lot of interaction with their peers, especially across career pathways. In the original course that was taught in a manner that did not provide choice of pathways, the instructor tended to enact PL for the students to compensate for the lack of this affordance in the course design. Finally, Tsybulsky (this issue) conducted a study of digital curation among high school students (i.e., development of a personal website to host content of their own selection), and found that the learning process in digital curation was often positively experienced by students. However, findings also revealed that when students engage in the more difficult parts of the curation (e.g., selecting information, writing an opinion piece) their experience was not as positive.

Several articles in the special issue focus on the opportunities and challenges that arise when scaling PL across an entire complex ecosystem. Carter (this issue) provides an account of ways PL can be enacted at a very large scale (i.e., through state policies in response to federal ESSA); however, he found that definitions and enactments of PL varied considerably. McCarthy and Liu (this issue) provide a richer accounting of such evidence of PL implementation, and demonstrate the effectiveness of a model of PL scaled through a district *Race to the Top* grant. Kallio et al. (this issue) provides additional insight into the ways PL can be adopted and accentuate the importance of organizational and leadership structures to scale PL.

Other articles focus on particular adaptive elements that are intended to make PL principles for curriculum design more efficient and scalable. McCarthy et al. (this issue) discuss how adaptive text selection that is automated is more feasible to scale than one-on-one human tutoring settings. Garrett et al.'s (this issue) method of have students choose in their own personally-meaningful dataset has affordances for scalability, as curriculum designers or instructors do not need to provide a large bank of different datasets that correspond to different interests. Alamri and Lowell (this issue) demonstrate that career-focused pathways can achieve an explicit, pragmatic personalization in a course for working professionals. When such courses provide these PL design features, course instructors experience less pressure to provide "ad-hoc" PL to make coursework relevant to students' career paths. This design feature systematically eases the burden of delivering such courses for instructors, and led to reports of increased engagement in an instructional setting where learners tend to be disengaged, and feel like they are "held hostage" (Phillips, 2014, p 7).

5. Major Issues for Personalized Learning Identified in Special Issue Articles

In this section, we discuss three major issues for PL that arose both in the special issue articles and from current discussions in the field of PL.

Issue 1: What is the role of technology in personalized learning?

Advances in technology have transformed personalized learning (Collins & Halverson, 2009). The 1:1 interactions of students with devices like tablets, netbooks, and mobile devices afford increased opportunities for PL within and outside the school day. The data that students' interactions with learning platforms produces can be leveraged to gain knowledge about students' knowledge, interests, and preferences, and other functions can be used to deliver educational content to students based on such information. For example, students' own data can be used to compare the learning behaviors they undertake, and whether those behaviors are similar to successful or unsuccessful students from past classes. When these data are available to instructors and learning support professionals, a personalized system can be enacted to predict success before major exams, and students can be provided with support before they begin to perform poorly (Bernacki, 2019).

Whereas technology provides ample potential, evaluations of the implementation of PL show there is still progress to be made. In their large-scale study that found positive learning gains for PL, Pane, Steiner, Baird, and Hamilton (2015) found that blended learning approaches were mainly being used for routine tasks like reading or accessing reference materials. In addition, despite exciting advances in augmented, virtual, and mixed reality technologies, and novel uses of tablet, wearable, and mobile technologies, most research on PL has been conducted using traditional computers (Xie, Chu, Hwang, & Wang, 2019). The articles in this special issue reflect such traditional uses of technology. Although tablets were utilized in some of the studies (e.g., Kallio, this issue), it is unclear whether the affordances a tablet has that a computer does not have (e.g., mobility) were being leveraged in a meaningful way. Plass's (this issue) conceptualization of adaptive learning, as well as reviews of mobile learning design (Bernacki, Greene, & Crompton, in press), describe the potential of location-aware technologies for implementing adaptivity based on the learner's current position. Plass also describes the potential of using learning analytics to allow stronger psychological measurement of real-time student-level variables (e.g., Baker et al., 2012; Walkington & Bernacki, 2018), as well as predictive modeling of educational data using artificial intelligence (e.g., Bernacki, 2019).

It is important to recognize that PL does not necessarily require the use of computing technologies (e.g., Walkington & Bernacki, 2015), and the role and relative importance of the technology itself varies greatly across implementations of PL. For the studies by Tsybulsky (this issue) and Garrett et al. (this issue), technology platforms acted as tools that students used to complete and compile their work while participating in an intervention or a series of rich tasks, without any sort of technology-based adaptivity to student characteristics. Alamri and Lowell (this issue) employed a similar approach that relied on learner's choices to provide PL that accommodated their goals, interests, and preferences. For some PL efforts such as adaptivity in iSTART (McCarthy et al. this issue), technology is indeed central to PL. iSTART served as the platform through which the learning materials were delivered, but technology was also used to adapt automatically based on student needs.

However, in studies like Kallio et al. (this issue), McHugh et al. (this issue), and McCarthy and Liu (this issue), technology platforms are conceptualized as one part of a larger, complex learning ecosystem that has become personalized in ways that extend beyond technological

infrastructures or tools, and beyond particular learning tasks. Technology tools such as learning management systems and enduring learner profiles are important pillars of this system, certainly, and instructional tasks that have PL elements within them may also play a role. But Kallio and colleagues (this issue) argue for a vision of PL which "open[s] the contemporary discussion of personalized learning from a narrow focus on learning technologies to an expansive vision of student-centered school reform" (p. ##). McHugh et al.'s (this issue) findings show this distinction nicely, reporting that K-12 students tend to equate PL with concrete procedural elements like particular technology tools and programs, while educators equate PL with abstract structures like goal-setting, support, and community, as well as the nature of the classroom environment and instructional tasks.

One important conception of the role of technology within a more expansive view of PL comes from Halverson et al. (2015), whose study of PL in PiP schools found that, rather than simply adding devices and software onto existing instructional programs, these schools created *socio-technical ecologies*, where an integrated and coherent set of technological tools was used to transform instruction and learning. The schools utilized information management and productivity tools, computer-adaptive curricula and assessments, as well as digital media spaces that helped students engage in creative work. In digital media spaces, students would choose how to represent their understanding and make their learning visible. Kallio et al. (this issue) similarly describe the process of school leaders developing an idiosyncratic technology ecosystem as critical to the implementation of PL. This ecosystem involved the use student-facing digital management systems and computer adaptive technologies for instruction and assessment.

Issue 2: To what degree are student ownership, voice, and choice important to the implementation of personalized learning?

Another topic that is salient in nearly all of the articles in this special issue is the role of student agency and control in PL. We framed PL according to the U.S. Department of Education (2016) definition, which states that PL approaches are meaningful, relevant, interest-driven, and often student-initiated. But the degree to which this part of the definition is enacted varies greatly, both in the articles in the special issue and in the implementation of PL at large.

Plass (this issue) differentiates adaptivity – when adjustments to the learning experience are controlled by the system, from adaptability – when adjustments are based at least partially on learner choice. He argues that the optimal design depends on the intended goals of the system and the theory that guides it. McCarthy et al. (this issue) explore this tension when describing their experiences with iSTART. The PL mechanism they explore allows the instructional system to select texts for learners in order to automatically adapt text difficulty to learner performance. McCarthy et al. discuss how they could have implemented a system where learners were permitted to choose their own texts, but that they had observed that the process of selecting texts was time-consuming for learners. Here adaptivity increases efficiency while adaptability might compromise it. Because they imposed a design choice to prioritize efficiency, it is not clear what trade-offs for learning may have occurred. Garrett et al.'s (this issue) results reveal a similar tension. This study allowed students to choose their own datasets based on their interests to analyze for course projects. However, as a result of this choice, the datasets were sometimes

messy and did not always represent the academic concepts from the course in a concise, elegant manner.

Project-based learning (PBL) is a well-known method to give students ownership, voice, and choice, and PBL is sometimes cited as one type of PL (e.g., Office of Educational Technology, 2010). Pane et al. (2015) found little implementation of PBL at PL schools, due in part to teachers' perceptions that these approaches are at odds with teaching grade-level standards to underprepared students. Tsybulsky (this issue) reports on the implementation of activities that share many characteristics with PBL and that are highly student-driven and adaptable. However, these activities were enacted in a special setting – Israeli schools where teachers did not have to follow a pre-defined curriculum for a portion of their school year and could use alternative assessments. It is unclear whether this kind of student-driven learning could feasibly be done at scale within traditional systems of schooling. Tsybulsky found that students had some negative emotions around the openness of the projects, and around having to present their own perspective. This echoes the work of Netcoh (2017), who studied open-ended student-driven projects in middle school classrooms within a district implementing PL in the U.S. He found that although students liked being able to choose a topic to pursue, some struggled with teachers providing bounds on their ideas, while others struggled with a perceived lack of structure from teachers.

This issue of allowing for student voice and ownership also shows up in approaches to PL centered around whole-school reform. Carter (this issue) comments that promoting learner agency is less of a focus in state ESSA plans, even though the research supports its effectiveness. Halverson (2019) distinguishes between educators at PL schools who focus on *learner interests*, where students take ownership of the goals and means of their learning, versus *learner needs*, where educators determine goals for students, often giving assignments in computer adaptive learning tools. The two articles in the special issue describing implementations as part of the PiP initiative (Kallio et al., this issue; McHugh et al., this issue) cite student voice and choice as a central element of PL. However, the theme of student agency did not come up in the analysis of student and teacher interviews conducted by McHugh et al. In addition, in McCarthy and Liu's (this issue) study, student voice and choice seems to be less accentuated in their definition and implementation of PL.

Issue 3: What challenges arise from a lack of consensus in the definition and theoretical grounding of personalized learning (both within studies and between studies)?

The concept of PL is complex, with definitions and enactments varying widely between researchers in different disciplines or with different foci (e.g., Plass, this issue, compared to Kallio et al., this issue), between enactors in different states and school contexts (e.g., Carter, this issue), and even within schools and initiatives as teachers, students, and researchers define and experience PL differently (e.g., McHugh et al., this issue). This lack of a consensus definition – which would include answers to key questions like "What is the role of student voice and choice in PL?" – creates a complex problem for research and practice. PL could be defined as individualization – which could be teacher-driven instruction focused on basic skills with automatic adaptivity (see Wolfe and Poon, 2015). It could be defined as leveraging students'

interests through automatic adaptivity (e.g., Walkington, 2013), or learner-driven content creation (e.g., Garrett et al., this issue), or strengths-based learning (McCarthy & Liu, this issue). It could be defined as PBL (e.g., Tsybulsky, this issue) or as an expansive school reform with any number of redesigned structural elements that work together (e.g., Kallio, this issue).

Although it may be advantageous to use an inclusive definition of PL that encompasses all of these, it also makes it difficult to compile and organize an evidence base that describes the designs and effects of PL in a way that policymakers, school leaders, parents, and teachers can use to make informed choices. Simply conducting a review on PL literature or a meta-analysis on PL effects would not be very useful to gauge whether PL is worth school's, district's, or state's investment, or how they might undertake it. When we see large-scale implementation results for PL reported (e.g., McCarthy & Liu, this issue; Walkington & Kamata, 2018; Pane et al., 2015; RAND Corporation, 2014), the results are difficult to interpret without a fine-grained understanding of what was actually going on in these classrooms. This difficulty is compounded when those who study PL implementations do not clearly define the features of their PL adoption, or do not measure and report the fidelity of their implementation. In some ways, the broadness of PL conceptualizations may be exactly why PL has proved to be transportable to schools. Different implementers can choose from a wide array of elements that resonate with their needs, the priorities of their leadership, and their culture; this is evidenced by the variety definitions and enactments of PL from state-to-state (Carter, this issue).

This situation is further complicated by the lack of explicit theories of learning guiding many PL implementations. Learning theories often become implicit as PL is implemented, and initiatives tend to focus on drawing upon the important practical experience of educators and leaders and on accounting for unique contextual considerations, rather than on formal theories of learning. Even when PL adheres to theories of learning, some of the theories that undergird PL approaches lack empirical support. For example, PL experiences aligning to students' "learning styles" are popular (Bernacki, Greene, & Lobczowski, working paper), but the evidence base that substantiates the existence of learning styles is sparse and often derived from weak research designs, and far more counter evidence suggests they do not exist (e.g., see Pashler et al. 2008; Rogowsky et al., 2015). In contrast, many other learning theories enjoy decades of evidence to substantiate their assumptions and inform their application to educational contexts. This research base can provide a deep understanding of implementation challenges and conditions of successful implementation (e.g., interest theory; see Renninger & Hidi, 2015).

6. Future Directions for Personalized Learning

We close our introduction by proposing some future directions that researchers and practitioners might pursue as they conceptualize and practice PL. These recommendations derive from the issues addressed in prior sections and that are highlighted by articles in this special issue.

Recommendation #1: Encourage PL implementers to clearly define their approach and articulate a theory of change that connects specific learner characteristics to learning environment changes to learner outcomes

Increasing transparency by pushing for clearer definitions of what PL is and what it looks like in different settings is essential. This can allow for the development of a well-instrumented evidence base that can guide future approaches to PL. PL designers and implementers should specify a theory of change at the outset of an initiative to determine how components are aligned to both student characteristics and features of students' learning environment. Implementers should specify the outcomes they aim to improve (e.g., achievement, career aspirations, academic motivation). Thereafter, they can consider theories and research that identify the learner characteristics that could be leveraged through PL efforts (e.g., learner knowledge, learner interests, learner motivation) to bring about this improved outcome. Then they can appraise the affordances and constraints within their learning environment and determine what kinds of changes to the physical environment or classroom practices (e.g., self-paced learning, project-based learning) must be made to accommodate learner characteristics, and leverage them to reach the intended outcome.

Recommendation #2: Implement design-based research that interleaves theory development with classroom implementation, and connects researchers to educators and leaders

In design-based research (Collins, Joseph, & Bielaczyc, 2004), researchers and practitioners "engineer" learning interventions and theories in synergy, with continuous adjustment and experimentation, in order to allow evidence-based claims to be made. Design research enables results to gain validity through the observed consequences of their use and for the richness of the social, naturalistic contexts to remain intact (Barab & Squire, 2004; Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003). Although design-based research has traditionally not been used for PL, it has many strengths. First, PL initiatives often involve many aspects of a school environment that are adjusted simultaneously (e.g., reorganizing spaces, implementing computer-assisted instruction, joint teacher/student goal-setting). Design research is ideal for investigating initiatives with this sort of complexity. Second, design research integrates learning theories, but in an *in vivo* manner where theories are continuously revised in concert with classroom use. Finally, design research involves partnerships between researchers, classroom practitioners, and educational leaders. Educational researchers are only sometimes heavily involved in PL research, despite the widespread implementation of PL in schools. Adopting researcher-teacher-leader partnerships for PL that use design-based research approaches could promote the sharing of knowledge about PL. Such partnerships would be most likely to form if they were an explicit part of funding structures for PL.

Recommendation #3: Collect more classroom observational data of how classroom learning environments change when learning becomes personalized, compared to non-personalized instruction

Most current research that compares PL to typical instruction focuses primarily on comparison of achievement test scores or other quantitative outcome measures. Teacher self-report measures of implementation are sometimes collected, as are teacher and student surveys. But missing is classroom observation data that captures in a rich, embedded, and concrete manner how instruction is changing when PL initiatives are enacted, compared to typical instruction. A deep understanding of the ways that various elements of curriculum, instruction, and assessment shift

when particular approaches to PL are implemented could provide much-needed guidance to those in schools and districts. The process of designing classroom observation protocols to assess PL initiatives could also benefit implementers. Establishing methods of collecting evidence can help to formalize a vision of what PL should look like in day-to-day classroom practices. A small collection of classroom observation tools that can measure classroom behaviors along Cuban's (2018) proposed continuum of PL could greatly advance the science of PL. These tools could facilitate comparisons across research studies and establish how different key elements of PL contribute to an initiative.

Recommendation #4: Conduct research and document evidence of ways authentic implementation of student control, choice, and ownership can be supported at scale

A central struggle in PL design is to determine how and when to allow student autonomy, agency, and leadership in their own learning processes. Educational research would suggest there are no clear answers to how to do this, but successfully implementing true learner control lies at the heart of PL, and is what will ultimately allow PL to achieve its promise. More research is needed that explores challenges that teachers experience when giving students autonomy and control (e.g., Tsybulsky, this issue; Netcoh, 2017), that explores the motivational and learning outcomes of students in these environments, and that gives useful guidance for teachers on how to manage these kinds of open environments. This research could answer questions such as: When student choice clashes with "covering" particular academic standards, how can teachers navigate this divide? How can a teacher set productive limits on the degree to which students can have autonomy? And how can teachers and leaders manage tensions between increased student autonomy and the rigor or scope of the academic content, and then communicate effectively about this to stakeholders?

Also needed is research that considers how individual differences and contextual factors might moderate the effectiveness of approaches accentuating student voice and choice. There are likely key learning situations that this approach is most powerful for, and figuring out which parts of the school curriculum could best leverage student-driven learning could more carefully target implementation. Finally, while individual case studies of how student-driven classrooms operate in particular environments are important, research that discusses these practices being implemented at scale within some of the constraints of typical school systems and with the buy-in of stakeholders will be particularly important. Research on PBL and maker-based learning will be useful to leverage here, as these approaches often involve high levels of student control.

7. Conclusion

The field of personalized learning has arrived at a critical juncture in its development. PL approaches are being broadly implemented in schools, and as implementation spreads, the research base that appraises these approaches needs to also grow and change. Researching PL is a daunting undertaking due to complex logistical and theoretical issues, including unclear definitions, variable implementations, and the implicitness of theories of learning. Research efforts are also challenged by the difficulty involved when substantive changes to traditional

structures of schooling are attempted: disarray can occur when educational interventions are scaled quickly across classrooms with varying levels of support, buy-in, and resources.

PL continues to provoke enthusiasm and excitement among teachers, leaders, and schools, but can provoke less enthusiasm from researchers. PL could be viewed as too variable in definition, too lacking in rigor, and too untethered to learning theory to be appropriate for empirical investigation. This gap between research and practice is likely to widen unless partnerships between researchers and PL implementers arise. We thus propose that the future of PL lies in researcher-practitioner partnerships that embrace learning theory, value the practice-based knowledge of teachers and leaders, identify and understand the unique affordances of different learning contexts, engage in collaborative design-based research, and employ rich observation of classrooms interactions. These are key to well-informed PL that that allows for deep, meaningful connections to be made to fine-grained learner characteristics and that enables students to take ownership of their learning.

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