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Personalizing Learning Through Precision Measurement

Janet S. Twyman

Personalized learning may be the most important thing we can do to reimagine education in this country.

Richard Culatta
U.S. Dept. Of Education Office of Educational Technology, (2013)

Promising to "meet each child where she is and help her achieve her potential" (Wolf, 2010, p. 6), personalized learning has become extremely popular in K–12 education (Cavanagh, 2014). The U.S. Department of Education emphasizes personalized learning as fundamental for student-centered, future-ready, 21st-century learning (U.S. Department of Education, 2010). State and local departments of education in Tennessee, Wisconsin, South Carolina, Michigan, Oregon, Texas, and others have created offices of personalized learning or launched personalized learning initiatives (Ventura, 2014). Several major foundations and national organizations are funding personalized learning programs, supporting personalized learning networks, or creating a myriad of resources and software programs. Personalized learning also seems to have some empirical support. A recent RAND study examining the use of personalized learning strategies across 11,000 students indicates promising results: While levels of implementation varied, in general, reading and math scores for students in schools using personalized learning strategies were substantially higher relative to national averages (Pane, Steiner, Baird, & Hamilton, 2015).

The mission underlying personalized learning and efforts to carry it out have a long history in public schools (Ventura, 2014). District-level policy suggesting educators adjust what, when, and how a student learns can be traced back to the late 1800s when Pueblo, Colorado's superintendent introduced a plan to enable students to move at their own pace. Not long after, in 1912, the San Francisco Normal School began promoting students based on demonstrations of mastery in a given subject. In *Democracy and Education*, John Dewey (1916) advocated placing the child (not the curriculum) at the center of schooling, which influenced the Dalton Plan and its encouragement of each

student to program his or her curriculum in order to meet his or her needs, interests, and abilities (Dewey, 1922). Within higher education, Fred Keller (1968) introduced the Personal System of Instruction (PSI) and its emphasis on student-paced mastery of content, digestible units of instruction, small-group tutoring, and formative assessments, garnering considerable credibility from empirical research (see Fox, 2004). National support for individualization and personalization for students with special needs appeared in 1990, with the Individuals with Disabilities Education Act (IDEA) and the requirement that an Individual Education Plan (IEP) consider each student's unique learning needs to determine learning goals and support needed. The 2010 National Education Technology Plan called for:

> engaging and empowering *personalized learning* [emphasis added] experiences for learners of all ages. The model stipulates that we focus what and how we teach to match what people need to know and how they learn. It calls for using state-of-the-art technology and Universal Design for Learning (UDL) concepts to enable, motivate, and inspire all students to achieve, regardless of background, languages, or disabilities. It calls for ensuring that our professional educators are well connected to the content and resources, data and information, and peers and experts they need to be highly effective. And it calls for leveraging the power of technology to support continuous and lifelong learning. (A. Duncan, in U.S. Department of Education, 2010, p. v)

Yet exactly what is personalized learning? Various organizations have similar, yet unique, definitions. The International Association for K–12 Online Learning (INACOL) states that personalized learning "is tailoring learning for each student's strengths, needs and interests—including enabling student voice and choice in what, how, when, and where they learn—to provide flexibility and supports to ensure mastery of the highest standards possible" (Patrick, Kennedy, & Powell, 2013, p. 4). The Glossary of Educational Reform (2015) refers to personalized learning as "a diverse variety of educational programs, learning experiences, instructional approaches, and academic-support strategies that are intended to address the distinct learning needs, interests, aspirations, or cultural backgrounds of individual students" (para. 1). Next Generation Learning Challenges (n.d.) characterizes personalized learning as "an education model where students are truly at the center, learning is tailored to individual students' strengths, needs, and personal interests. Learning opportunities take into account existing knowledge, skills, and abilities, set high expectations, and push students in supportive ways to reach their personal goals" (para. 1). Wikipedia (n.d.) tells us that personalized learning is the tailoring of pedagogy, curriculum, and learning environments by learners or for learners in order to meet their different learning needs and aspirations with technology—used to facilitate personalized learning environments.

Yet exactly what is personalized learning? Various organizations have similar, yet unique, definitions.

While these definitions all seem to refer to desirable goals in education, what does personalized learning really mean for the classroom? What do the different descriptions and terms entail? If we deconstruct Wikipedia's definition: *Pedagogy* is the method and practice of teaching and involves how the teacher delivers instruction, manages classrooms, motivates students, encourages learning-to-learn skills, and the like. *Curriculum* refers to the specific lessons and content to be taught. *Learning environments* are "the diverse

physical locations, contexts, and cultures in which students learn" (Glossary of Educational Reform, 2013a, para. 1). A *learning need* is defined as an identified gap between the required or desired knowledge or capability and the actual knowledge or capability of the learner (Glossary of Educational Reform, 2013b), which is made more complex by differing types of context-driven learning needs. Finally, Merriam-Webster (n.d.) defines *aspirations* as "a strong desire to achieve something high or great" (para. 3).

Each of these components is highly complex on its own, requiring expertise, resources, and support to understand and implement. How does a teacher gain such pedagogical expertise? What is an effective curriculum, how do we know, and when and how do we use it? How can supportive learning environments be created and maintained? How does one determine learning needs, especially when needs may be of different types and context driven? And of course, aspirations can be very hard to discern; often one is not fully aware of one's own desires, let alone those of others. Creating a milieu that accomplishes all these things would be challenging for a teacher of a single student, exponentially more so for a class, a school, or an entire system. So how do we personalize learning, for each individual student, across subject matter and grade level, for all students? This chapter proposes that **precision measurement aided by technology and integrated with a strong relationship between the student and a caring teacher is instrumental in achieving the goals of personalized learning**.

Let us consider one more perspective on personalized learning. As defined by the Center on Innovations in Learning, personalized learning involves

> the use of multiple instructional modes to scaffold each student's learning and enhance the student's motivation to learn and metacognitive, social, and emotional competencies to foster self-direction and achieve mastery of knowledge and skills. Personalization ensues from the relationships among teachers and learners and the teacher's orchestration, often in co-design with students, of multiple means for enhancing every aspect of each student's learning and development (see Murphy, p. iii, in this volume).

It is the centralizing of the relationship between teacher and student and the deep understanding of instruction, in what and how to teach and learn, that ultimately personalizes instruction. Refining the popular personalized learning phrase "variation in time, pace, and place," this chapter proposes that, with the competent guidance of a caring teacher armed with astute technology, ***true personalized learning varies the time, place, path, pace, practice, and trace of learning for each and every student*** (Twyman, 2015). After briefly describing time, place, path, pace, practice, and trace, this chapter's primary focus will be on how precision measurement makes truly personalized learning possible.

Time. *Time,* or "seat time," refers to the amount of time students are required to be in a course or grade and historically has been tied to funding and student progression. Traditionally, time has been held constant (i.e., quarters, semesters, grade-level year) while individual student outcomes during that time varied widely. Personalized learning, especially in a competency-based form (see Twyman, 2014a), does away with time-based requirements in favor of individual student advancement upon mastery. It also supports the notion of "anywhere, anytime" learning, which occurs outside the traditional classroom at any time of the day.

Pace. *Pace* is the rate at which something progresses; in education it is the speed at which progress is made through a particular curriculum or instructional program, such

as the number of days a student takes to master one unit on the Civil War. Instructional pacing is the speed at which a teacher presents a lesson, with most scholars advocating a brisk pace to enhance student attention, increase responding, and decrease off-task behavior (Lignugaris-Kraft & Rousseau, 1982). Historically, educational progression has been lock-stepped, with an entire class moving through a unit in the same amount of time, often dictated by the organization of the textbook or some other structural concern. Within personalized learning, pace is determined by individual progression and is not a reflection of ability (i.e., fast = smart; slow = less smart) but rather a dimension of how a particular student may cover particular material at a particular time.

Path. *Path* refers to the route a student takes to move towards his or her learning objectives. A learning pathway indicates the specific course of study and experiences a student has on the way toward his or her specific goal, such as graduation. In a personalized learning system, schools offer many pathways, including different courses, programs, and learning opportunities in and out of school so that each student may create his or her own goal path (Glossary of Educational Reform, 2013c). Learning pathways incorporate diverse educational options both outside of typical school settings (e.g., work-study, community service, internships, apprenticeships, online instruction, or even travel), as well as from more traditional learning experiences, all under the assumption that relevant learning accomplishments are to be recognized and valued equally wherever students achieve them. Personalized learning adds further refinement to learning pathways, moving from choices that are offered by the school to opportunities that are created by the student, supporting greater flexibility and customized learning experiences based on specific interests or needs (Glossary of Educational Reform, 2013c) and supporting student ownership of learning (Secondary School Consortium, n.d.).

In personalized learning, teachers vary their practice based on the needs, interests, performance, and goals of each of their students…

Place. No longer is schooling required to happen inside the classroom. The *place* of learning can vary widely, including within or outside the bricks-and-mortar school building, students' homes, the community, places of business, and so on. As part of "anywhere, anytime" learning, the advent of digital technologies makes anyplace learning truly possible.

Practice. *Practice* refers to what the educators do to facilitate learning—in other words, the actual application or execution of teaching. On a larger scale it may also refer to the implementation of policies at the school, district, or state level and the tools and systems to support them (such as schoolwide data systems or a state waiver of the Carnegie unit). For better or worse, K–12 education proffers a myriad of educational interventions—practices to be implemented by educators—but offers little specific guidance on what practices to use, when, with whom, under what conditions. The growing field of educational data mining and predictive analytics (see Baker, 2013; Baker & Yacef, 2009) may soon change that; however, educators should always avail themselves of an array of evidence-based strategies and tactics (teaching practices) to have at the ready for use with each of their unique and diverse students. In personalized learning, teachers vary their practice based on the needs, interests, performance, and goals of each of their students, making the interactions between teacher and student one of the ultimate ways to personalize learning. The practice of personalizing learning can be complex, with

the responsibility both on the teacher and on the student. Initially the student may help inform which best teaching practices might be needed based on his or her current level, goals, and interests. Once implementation of that practice has begun (the act of teaching), the student provides information on the effects of that practice based on his or her learning gains and motivation.

Trace. The effects of practice lead us to *trace*, or what remains as and after teaching occurs. How do we know when a student has learned something or, perhaps more importantly, if a student is learning? Trace is the objective, notable change that comes from teaching and learning and requires some form of detection (i.e., perceivability, recognition). Detection may be in the form of direct or indirect observation, formative assessment (see Andrade & Cizek, 2010), alternative assessments (see Herman, 1992), or in the multitude of ways learning can be validated in competency-based education (see McClarty & Gaertner, 2015). Trace may be uniformly measured (as in standardized assessments); however, its measures are probably best determined by individual context. It should be observed frequently and in real time (as found in formative assessments). Trace may be represented as a permanent product (as found in student portfolios or project-based learning), recorded automatically (as found in some computer-based instruction), represented by other means (such as grades or badges), and detected by either the teacher or student (preferably both) using some form of measurement. In other words, trace is not one thing, but represents the numerous empirical, actionable methods to indicate a learner's current status and progression, in context.

Measurement in Education

Trace relies heavily on measurement. In education, few terms evoke more emotion and opinion than measurement. Critics equate it with rather unpopular items like accountability, standardized testing, or narrowing the curriculum (i.e., teaching to test, blind memorization, or rote learning) and tie it to policies often perceived as punitive, such as adequate yearly progress, value-added teacher evaluation, or student tracking (see Popham, 2000). Measurement has been accused of being a woefully inadequate means of getting at what really matters in education. However, the premise of this chapter is that measurement is essential to any earnest teaching (or learning) effort. Without it we cannot truly or well personalize instruction for any student, let alone for all students. When done well and for the right reasons, measurement is one of the most caring and beneficial acts teachers can do.

Known instances of formal assessment (a form of measurement) first appeared in America's public education system in 1642 with the passage of the Massachusetts Bay School Law requiring children to know the principles of religion and the capital laws of the commonwealth. Given the overall purpose of schooling, it seems some form of measurement is inevitable (Ross, 1941). Edward Thorndike, the father of modern educational psychology, recommended collecting qualitative information to help teachers address practical educational problems (Beatty, 1998). The last 50 years have seen a move towards greater accountability for student learning and developing a "culture of evidence" within schools (Shavelson, 2007). In a departure from the longstanding proxy for student performance (i.e., graduation rates), schools are pushed to measure learning more directly, with both specificity (at the level of standards or learning objectives) and broadness (across curriculum domains and subject matter). Measurement now focuses on "the

common aims of (a) arriving at defensible conclusions regarding students' standing with respect to educational outcomes deemed important, (b) documenting student achievement, (c) gauging student progress, and (d) improving teaching and learning" (Agger & Cizek, 2013, para. 1). It is in the last two categories that personalization comes into play. While evidence of student learning is important, even more so is knowing what that evidence means and how to act on it. These are the core questions regarding a student's educational experience and the personalization of learning.

It may be useful to consider the difference between measurement, evaluation, assessment, and evidence, as understanding the differences is most beneficial and may be instrumental in teaching effectively (Kizlik, 2015). Most commonly, measurement involves the process by which the attributes or dimensions of something are determined, usually using some standard instrument or scale. Measurement involves collecting information using some sort of standard metric and implies some level of knowledge in how to use the scale and understand the results (an example provided by Kizlik, 2015, involves a person with no knowledge of Ohm meters applying one to an electrical circuit and unable to understand the results). Measurement provides us with evidence, which is a clear, objective indication often used to inform (or support) a conclusion. Relevant to education, Slavin (2015) asks quite succinctly: "How can we use evidence to make sure that students get the best possible outcomes from their education?" (para. 9).

Considering evidence from what has been measured moves us into the realm of assessment, or the systematic collection, analysis, and interpretation of information relevant to a particular outcome (Suskie, 2004). Various types of assessments are specifically designed to yield information relative to the question being asked (e.g., standardized assessments are administered and scored in a predetermined, standard manner, often to answer larger scale comparative questions; summative assessments are used to evaluate student learning at the end of an instructional unit or period of time and answer post hoc effectiveness questions; formative assessments are used while the learning activities are in progress and answer questions about current teaching effectiveness; see Layng, Stikeleather, & Twyman, 2006). It is when we assign some value to assessment that we arrive at evaluation or the process of making judgments based on assessment and evidence (Levine, 2005).

For example, let's consider a third-grade spelling lesson of 10 words, taught in the more traditional manner of repeated writings of the words, writing sentences containing the words, and an end-of-the-week quiz. Let's also consider the same 10 words taught using interactive digital media where the students solve games using the words, use them in an animated story, and test out on each word individually when ready. We **measure** the number of words spelled correctly by students across both conditions. This is **evidence** gleaned from the two conditions. When we look at the number correct compared to our goal of 10 words, we are making an **assessment**. When we compare those results, either to what students knew previously or between the two conditions, and make a statement about which is better, we are **evaluating** the evidence. Thus, measurement, in and of itself, does not involve judgment of the results. Additionally, although assessments are used to evaluate educational progression and inform decision making, their administration often involves contrived circumstances, necessitating inference about the results in relation to what a learner actually knows (Kizlik, 2015). Understandably, this injects skepticism into the picture. In a survey of five teaching cohorts, Miller (1998,

cited in Mehrens, 1998) found that only 11.3% to 54.7% of public school teachers believed the state-mandated standardized assessments have had a positive effect on student learning, with even fewer, 13.1% to 28.7%, viewing the results as an accurate reflection of student performance.

Assessment results are often morphed into some form of statistics or average to inform our understanding of student ability. In determining what works best for which students, when, and where, the use of statistical averages poses an often-unrecognized yet persistent problem: There is no such thing as the average learner. Averages tell us nothing about an individual child, nor do they give us any indication of what worked or didn't work for that, or any, individual. As noted by Rose (2016) in *The End of Average*, it is not possible to draw any meaningful conclusions about a particular human being when using statistical averages, yet schools are designed to evaluate and recognize learning based on comparisons to the average learner, a mythical notion of a one-size-fits-most model that ignores individuality. Rose (2016) provides a useful example:

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In the 1950's the U.S. Air Force was investigating why pilots were struggling to control their planes. They determined it had nothing to do with training or pilot error, but instead the way the cockpits had been designed since the 1920s—to fit the 'average' pilot. In the 1920s, when military aviation was under the command of the U.S. Army Air Service, over 4,000 pilots were measured across 10 dimensions, assuming most would be within the average for most dimensions and expecting many would fit all 10. In actuality, none of the pilots fit the average size profile. Designing cockpits for the average man resulted in jets designed for no one. This discovery brought the Air Force to an adaptable design, leading to the invention of the adjustable seat (an innovation that is now commonplace). Likewise, in our efforts to support personalized learning, we must change our emphasis from the average learner and standardized assessment to that of individual learners and precision measurement.

Precision Measurement

What is meant by precision measurement? Precision yields consistent results when repeated and represents a high level of correspondence between the measured value and the "true value" based on the reproducibility of results. When "precise," one is exact, accurate, and careful about the details, and it conveys a sense of quality. We need that level of exactness, detail, and quality when caring and doing something about the learning of our students. Precision measurement done in real time, as teaching and learning are occurring, can empower both teachers and students by moving away from the rather inefficient (with regard to effecting learning) practices of statistical averages of learning, post hoc testing, and instructional decision making after the teaching is done. Precision measurement is the rational outcome of the combination of recent guidelines, such as evidence-based practice and data-based decision making; of known strategies, such as formative assessment and curriculum-based measurement; of lesser known areas, such as precision teaching and behavioral education; and of new possibilities that arise from educational data mining and learning analytics.

If, as suggested, precision measurement—aided by technology and supported by a strong relationship between the student and teacher—is instrumental in achieving the

goals of personalized learning, then it is important to know exactly what precision measurement is. This chapter posits **precision measurement as the real-time, in situ collection of relevant evidence regarding the current state and progression of a student's knowledge, abilities, and attitudes—evidence to be used in making meaningful, moment-to-moment, individualized decisions about what and how to teach and learn.** It is based on these premises:

a. The **learner** knows best;
b. **Teacher** relationships with students are critical;
c. **Measurement** imparts understanding; and
d. The best **technology** is indentured to the service of decision making.

Consider this example: "Juan" was in a middle school science class learning about states of matter and applying various forces to demonstrate how molecules change matter into different states (solid, liquid, gas). Juan was interested in chemistry and liked working in the lab. Out of a variety of resources curated by his teacher and class, Juan chose to do a web-based interactive simulation,[1] adding and removing heat to watch different types of molecules form a solid, liquid, or gas and monitoring the relationship of the temperature and volume of a container to its internal pressure in real time. His goal was to relate the interaction potential to the forces between molecules. The program provided detailed information on the variables at work; peppered Juan with just-in-time "big picture" and specific questions about what he was learning; provided him with timely, real-world feedback on his experimentation; and kept a log of all his efforts, including what he tried and what did and didn't work, the types of errors he made, how quickly he worked through things, his chosen sequence of tasks, and so on. Juan had access to a steady flow of information about his learning, which he used to revisit some experiments. He and his teacher reviewed the log often, and considered its reflection of his metacognitive skills and how it fit in with his other learning. Juan soon saw that he didn't always attempt all experimental variations and that he was struggling relating a pressure–temperature diagram to the behavior of molecules. He wanted help interpreting the graphs of interatomic potential. His teacher, knowing of Juan's shyness, suggested a project with a classmate who was also interested in chemistry. They jointly created a video using materials available in the school and community that demonstrated how forces on atoms relate to interaction potential and embedded questions and answers about the graphs from their experiments to show their understanding. Juan realized that he wanted to do more field-based work in chemistry and science. We'll return to this example as we consider the premises of precision measurement.

The Learner Knows Best

All too often, students are relegated to a passive role in their own learning, plied with information that will be "on the test" (DeWitt, 2014). Two key tenets of personalized learning involve giving students "voice and choice" in their learning (Ripp, 2015), thus increasing their decision making and personal responsibility within the instructional process. "Voice" acknowledges a student's interests, values, opinions, perspectives, or ambitions; "choice" often refers to curriculum methods, time and place of learning, and

[1]This lesson is adapted from http://phet.colorado.edu/en/simulation/states-of-matter (log in required).

even what to learn. While each of these are important to personalized learning, a perspective incorporating precision measurement would arm students with the knowledge and tools to speak coherently about their learning and make informed choices.

In our example with Juan, he "knew best" with regard to his personal interests and aspirations and expressed his preference about what to learn and how to learn that new information and even how to demonstrate that knowledge. He was supported by precision measurement, not only by the data provided within his web-based experiments, but also by the data showing which concepts he knew well and where he needed further understanding. He used those data to choose which concepts to review or when to conduct additional experiments and saw his understanding improve immediately and over time.

Precision measurement is a vehicle for students to use their own data to make decisions, determine what they should do next, and challenge themselves to do better. Feedback on progression towards a chosen goal is highly motivating to students (Hanover Research, 2012). Students who track their own progress forward are more likely to make greater gains toward reaching their goals than students who do not, as indicated by a 32% gain in achievement found in a recent meta-analysis of research by Marzano (2010). Research indicates that individuals are motivated by success and competence, thus precision measurement and continuous assessment can enhance motivation in these ways:

- Emphasizes progress and achievement rather than failure;
- Provides feedback to move learning forward;
- Reinforces the idea that students have control over, and responsibility for, their own learning;
- Builds confidence in students so they can and need to take risks;
- Maintains relevance and appeal to students' imaginations; and
- Provides the scaffolding students need to excel (Hanover Research, 2012, p. 13).

Many believe a measurement and technology approach to personalization involves gathering data on what the student knows and can do, using algorithms to validate the information and set goals for learning, and determining a unique set of learning experiences from those analyses (Wiley, 2015), all of which result in an individualized, yet prescribed, learning path for the student. While likely effective, such systems run the risk of diminishing the rich opportunity to learn for oneself what to do next, perhaps even eliminating the learner's active role in this "personalized" method. A better model continues to involve data on what the student knows, yet also presents a comprehensible view of that information and requires students to consider and make decisions for themselves. Because precision measurement highlights ongoing performance relative to identified goals and other variables, it becomes the basis on which the student and teacher may decide what to do next—a critical form of voice and choice that is linked to higher order self-management skills (Lindsley, 1990). It has been shown that when students have access to their data, they play a larger role in choosing their own learning paths (Darling-Hammond, 2010).

Student voice and choice has roots in the concept that "the learner knows best" (Lindsley, 1972), with a difference in that "knowing best" is connected to data and analysis and not a general sense of "voice and choice." The data indicate what is working and what is not. If a student is progressing well as demonstrated by the charted data and other observed and measured variables, then the program is appropriate for the student;

conversely, if there is little or no progress or other observed variables are less than ideal (e.g., affect, attendance, alternative behaviors), then the instructional program or other variables must be changed (Binder & Watkins, 1990). The learning experience must "work" for the student. However, it takes a thoughtful and informed analysis of this information to improve the experience, best done by the teacher and student in concert. It is the role of the teacher to which we will turn next.

The Teacher–Student Relationship

Teacher relationships with students are critical. While evidence-based practice is based upon research on effectiveness, it becomes actionable and powerful when integrated with teacher expertise and a thorough understanding of a student. This understanding comes not only from multiple sources of information, but also is built upon a history of interaction, caring, interest, and support (Redding, 2013).

Precision measurement supports this relationship. In our example with Juan, his teacher could have simply identified the standard to learn and the myriad of "educational" resources available in school or online and left it to Juan to determine exactly what and how he was to learn. Instead, his teacher served as a guide through not only his study of states of matter, but in how to focus on his strengths and interests, what resources were available for concept learning and practice, which student might serve as a good partner for the project, and how to interpret and respond to data about his own learning. In this world of fingertip-ready information, learners need an advisor to help them learn to understand and organize information, comprehend complexity, write coherently, solve problems, work well on their own and with others, contextualize their own thoughts, reason productively, manage their own behavior, maintain positive motivation, and even persist in the face of difficulties (Slavin, 2016).

While noting the importance of warm and caring relationships, White (1986) further contends that "in order to be responsive to the pupil's needs the teacher must be a student of the pupil's behavior, carefully analyzing how that behavior changes from day to day and adjusting the instructional plan as necessary to facilitate continued learning" (p. 1). Precision measurement enhances this aspect of the teacher's role and perhaps changes it from that of an encyclopedia of transferable knowledge and deliverer of evidence-based procedures to that of an aware, motivating, and engaging learning guide who uses objective, in-the-moment information to ensure students become eager, competent, and self-reliant learners (see also Slavin, 2016). Before we can transform classrooms into places where students determine their own learning paths and take responsibility for their progress, teachers must understand how to plan, lead, and manage personalized learning (Grant & Basye, 2014), including knowing "academic strengths and weakness as part of a complete learner profile that gives a holistic view of each student" within an assessment process that is "embedded within each lesson and used as a tool for immediate and consistent feedback" (Mead, 2015, para. 2).

These practices are related to data-based decision making; personalization relies heavily on teacher ability to conduct formative assessments and ongoing progress checks so that they may adapt instruction to student needs (Hamilton et al., 2009). However "as data systems become more readily available to teachers, the ability to pose questions that generate useful data will become increasingly important" (Means, Chen, DeBarger, & Padilla, 2011, pp. 13–14). It is in this vein that precision measurement enhances

and extends the critical practice of formative assessment and using data to personalize instruction to using empirical information to better understand and serve the "whole learner," not just the instructional problem at hand. Teachers (and learners) who pose questions that generate useful data will not simply be asking how many answers are correct, but deep, humanizing questions that support individual learning and growing. Those types of precision measurement questions will be described next.

Measurement Imparts Understanding

The premise is simple: The more a teacher knows about a student, the better he or she is able to personalize instruction and help that student. The more current and relevant that information is, the better the help is likely to be. In our example with Juan, precision measurement facilitated his teacher's (as well as his own) specific awareness and deeper understanding of his needs. This instantiation of measurement is not about compliance or punitive accountability, but is about using empirical evidence to better understand a student. We do this by measuring what matters. As noted by Shavelson (2007), cultures of evidence "will not automatically lead to educational improvement, if what counts as evidence does not count as education" (p. 1). We need to tie our measures to improved outcomes for all learners. It is widely acknowledged that technology enables personalized learning, involving sophisticated measurement systems that dynamically track, analyze, translate, and illustrate data to not only inform the student and teacher but also to help determine the instruction, tools, content, and other learning variables best suited for each student—all working together seamlessly (Hanover Research, 2012).

> *Effective collection of, analysis of, and responsiveness to student data is central to the development of personalized learning environments at all grade levels.*
> *(Hanover Research, 2012)*

In practically all aspects of life, data support our decisions and increasingly help us personalize our experiences (e.g., when music streaming services suggest particular songs based on listening history or when shopping sites make purchase recommendations based on data from purchases, browsing, and other sources). The same is becoming true for education. The forms of precision measurement may be different depending on context (e.g., who and what is being taught, where learning is occurring, what technology resources are available), yet each form shares these common features:

- supports decision making and choice
- informs knowledge and understanding of the student or situation
- is used to understand and alter teaching practices or other variables
- aids a "bigger picture" perspective
- provides immediate, actionable information to teachers and students
- occurs frequently (continuous or ongoing)
- may be embedded or additive
- is empirical, based on direct or indirect observation, real-time or permanent product
- is reliable and valid

We know better evidence of learning is important, and even more so is knowing what to make of and how to act upon that evidence (Shavelson, 2007). Obviously precision measurement isn't simply measuring how well a student is doing the variables related to

content knowledge, but repertoires related to the ability to problem-solve and extrapolate, work fluently and with generativity (a form of creativity, see Johnson & Layng, 1992), persevere under difficulty, and the many other interpersonal or "soft skills" currently referred to as grit (Duckworth, 2007), growth mindset (Dweck, 2007), or personal competencies (Redding, in this volume). Each involves potentially measurable variables that affect learning (many are still being identified), which can be strengthened to improve student learning and well-being. Aided by technology, this type of measurement supports the building of interactive programs that recognize, match, and support critical factors that influence how individuals learn (such as psychological factors, the impact of emotion on learning, or relationships between humans and the learning environment; Martinez, 2001). With this type of information, teachers can predict and alter key instructional variables, such as the type, timing, and sequencing of instructions; stimulus discrimination and generalization procedures; fluency and resistance to distraction or forgetting; or the effects of temporary, automatic, or natural social consequences. (See both Crean-Davis and Layng in this volume for further discussion on the measurement and teaching of these variables and Baker for the use of predictive analytics in personalized learning.) If we consider personalized learning to be more than a reflection of a student's interests, goals, and motivations, then measurement of the dimensions presented above *is vital for truly personalized learning.*

Technology in Service to Decisions

The best technology is indentured to the service of decision making. While the concept of personalized learning has been around for some time, advances in digital content and delivery have placed personalized learning within reach for an increasing number of students, teachers, and schools. The flexibility inherent in digital technologies supports student-directed learning, improves interest and engagement, and provides multiple learning opportunities to maximize understanding (Hanover, 2012). As noted by Greaves (cited in Demski, 2012, p. 2), "if the students are leading their personalization via technology, then their instruction can be personalized based on a hundred variables instead of one or two." Technology supports personalized learning in a number of ways: students can use interactive, innovative teaching software and applications to learn at their own pace; assessment and monitoring of student progress can occur in real time; and students can interact with course material at any time, from anywhere (Hanover Research, 2012). These features, while beneficial, refer mainly to the technology of tools (i.e., digital devices and their capabilities) and not necessarily to the process of teaching and learning (i.e., software and algorithms; for more information on the distinction between technology tools and process, see Layng & Twyman, 2013, or Twyman, 2014b). While the capabilities of digital tools to conduct and support precision measurement are essential, it's their ability to enhance decision making that ultimately helps personalize learning. In our example with Juan, technology tools supported his access to a wide range of curriculum content which he could use anywhere and measured both his experimentation and his own progress. The technologies that supported the process of teaching and learning guided him using high-quality, adaptive instruction, vetted by his teacher, matched to his interest, and tuned to his current knowledge level. It also provided him with information on his own learning that allowed him to stretch his cognitive and creative boundaries, engage in problem solving, and make meaningful decisions.

Much attention is paid to educational software's ability to prescribe learning paths, differentiate and individualize instruction, and hone in on and extrapolate from patterns in responding (Horn & Staker, 2011). Often called adaptive learning or intelligent software (e.g., Knewton, Cognitive Tutor, Lumen, etc.), these programs respond to a student's interactions in real time by automatically providing individualized support (Blair, 2016). Early research has shown that an automated personalized curriculum sequence (based on pretest scores) providing a concise learning path and modifying instruction based on course difficulty was superior to conditions in which students freely browsed learning content (Chen, 2008). In a blog posting, Feldstein (2013) discusses adaptive learning software; here are a few examples drawn from that posting:

- A student using a physics program answers quiz questions about angular momentum incorrectly, so the program offers supplemental materials and more practice problems on that topic.
- A history student answers questions about the War of the Roses correctly the first time, so the program waits an interval of time and then requizzes the student to make sure that she is able to remember the information.
- A math student makes a mistake with the specific step of factoring polynomials while attempting to solve a polynomial equation, so the program provides the student with extra hints and supplemental practice problems on that step.
- An ESL writing student provides incorrect subject/verb agreement in several places within her essay, so the program provides a lesson on that topic and asks the student to find and correct her mistakes.

Intelligently designed software that automatically adapts to each learner may be an instructional game changer; however, precision measurement embedded into technology does not mean that the technology makes all the decisions for the teacher or student. Even instructional decisions, such as the examples listed above, should be left only to software that has been tested and validated and whose educators understand the underlying decision-making pedagogy. Technology to support personalized learning should not be solely focused on automatically selecting, sequencing, and presenting just the right information for the learner at just the right time, a situation which may result in a learner simply sitting back and clicking with no judgment or thinking required (Wiley, 2015); it must, at a very minimum, provide the basic information upon which its users can make informed choices.

> *"Technology alone isn't going to improve student achievement. The best combination is great teachers working with technology to… engage students in the pursuit of the learning they need."*
>
> *U.S. Secretary of Education Arne Duncan (2010)*

With the guidance of an informed teacher, technology that enables precision measurement should provide the conditions learners need to develop the skills required to successfully navigate their learning pathways and the information-rich world around them. As noted by Wiley (2016):

> Rather than making complicated decisions on behalf of students in a black box, these systems should surface their data and support students in evaluating them and making their own decisions about what and how to study….In the long run, the true power of adaptive and personalized systems will only be realized when they are designed to simultaneously support student learning in the discipline and increase human agency,

giving students and faculty the chance to develop their metacognitive and pedagogical skills rather than contributing to their slow demise.

Hence the true power of precision measurement in the education technology process is its potential to help us make better decisions and thus become better decision makers, in education and in life.

Caveats, Considerations, and Conclusions

Like the promise of personalized learning, the potential of precision measurement to enhance learning and student outcomes is great. However, as a whole, K–12 education is not quite there yet. A first hurdle is concern and fear around data and measurement. Before considering precision measurement, the reasons for measurement should be addressed. Measurement should never be used as the lever to punish or discredit anyone or anything, including the school or the curriculum, as is too often feared (Levine, 2005). It should not be a form of educational accountability (Browder, 1971). Using precision measurement as an essential tool to make decisions about instruction may go a long way to alleviating these concerns.

This better understanding and use of measurement should be a part of professional development, another hurdle in our quest. Even teachers who regularly use performance or formative assessments, including informal observation or paper-and-pencil responses, in making day-to-day classroom decisions, believe that more training is needed in the competent use of data and making educational decisions (Kershaw & McCaslin, 1995). Related are concerns about how to share data with parents and involve both them and the student in the decision-making process, highlighting the importance of clear, meaningful data and the need to foster a culture of support for precision measurement and its use in enhancing learning and student outcomes. Directly teaching data-based decision-making skills to educators, students, and parents is essential.

Lack of common data standards and concerns about data ownership and privacy pose other hurdles. Educational data systems do not always employ interoperability standards (i.e., a system's ability to work with other systems without special effort by the user) that would support secure, easy sharing of information between educators, schools, districts, states, students, and their families. This means educators are missing significant opportunities to use data to improve and personalize learning (U.S. Department of Education, 2016); however, national interoperability standards are being proposed and tested to improve the quality and effectiveness of technology-enabled tools and resources. Additionally, educators and policymakers around the country are rightfully concerned about the protection of students and their families. At least 46 states have introduced bills addressing student data privacy, and 15 states have passed new student data privacy laws (Data Quality Campaign, 2015). For example, California's Student Online Personal Information Protection Act requires developers to meet cyber-security standards, prevents the selling of student data for advertising purposes, restricts student profiles for non-educational purposes, and requires deletion of student data at school or district requests. Questions of who owns the data, how to use it to do the most good, and how to protect the individuals and systems on which the data are based are questions facing us now, and in the coming years.

The time to act is now. Educators are acutely aware of their responsibility to ensure that all students master critical content, and they strive to do this with specific and evolving

plans that incorporate the varied abilities, needs, interests, and performance of each student. Effective, caring educators don't enter a classroom simply "hoping" their students will learn—they avail themselves of everything they have to ensure student learning; "[t]he possibility of student learning needs to rely on something sturdier than 'hope'" (Meyer, 2016). Precision measurement underpins a teacher's ability to answer the question, "What does *this* student need at *this* moment in order to be able to progress with *this* key content, and what do I need to do to make that happen?" (Tomlinson & Imbeau, 2010, p. 14). If we do believe in the promise of personalized learning, then we must realize that personalized learning is something educators DO, and precision measurement supports that doing. Precision measurement aided by technology and integrated with a strong relationship between the student and a caring teacher is instrumental in achieving the goals of personalized learning. Variation in the time, place, path, pace, practice, and trace of learning is essential for each and every student. It is the trace of learning, in the form of precision measurement, that provides educators with real-time, relevant evidence regarding a student's progression of knowledge, abilities, and attitudes, so that together they can make meaningful, moment-to-moment, individualized decisions about what and how to teach and learn.

Action Principles for States, Districts, and Schools

	SEAs	LEAs	Schools
General			
Create and maintain a portfolio of personalized learning/precision measurement exemplars (at the district, school, teacher, and student level) to inspire and serve as a model and mentor for others.	♦	♦	♦
Foster a culture of support for precision measurement and its use in enhancing learning and student outcomes.	♦	♦	♦
Support small or rural communities with the development of district consortia to foster personalized learning grounded in precision measurement and enhanced by technology.	♦		
The Learner Knows Best			
Focus on students and learning; use that focus to determine what each learner needs to succeed, develop the systems of support for that need, measure and evaluate the success of that support.	♦	♦	♦
Encourage, teach, and support students to examine their own data, using it to set, modify, and reach learning goals.	♦	♦	♦
Provide supports for precision measurement and continuous assessment to enhance student motivation.		♦	♦
Teacher Relationships With Students Are Critical			
Make precision measurement an essential part of an ongoing cycle of improvement.			♦
Provide supports for precision measurement and continuous assessment to enhance educator motivation.		♦	♦
Provide job-embedded professional development focused on using data for instructional improvement and student achievement.	♦	♦	♦
Build and embed teacher evaluation frameworks that support evidence-based decision making and foster personalized learning.	♦	♦	♦

	SEAs	LEAs	Schools
Measurement Imparts Understanding			
Establish a clear vision for data use; develop and maintain a location-wide data system.	♦	♦	♦
Provide supports that foster a data-driven culture.	♦	♦	♦
Make data part of an ongoing cycle of instructional improvement.	♦	♦	♦
Teach students to examine their own data and set of learning goals.			♦
Provide ongoing and regular feedback, including, at a minimum, frequently updated individual student data that can be used to determine progress toward mastery.			♦
Ensure that LEAs and schools use interoperable data systems (e.g., student information, instructional improvement system, human resources, and budget data).	♦	♦	♦
Collect relevant, actionable data on enrollment, participation, progress, completion, and learning outcomes.	♦	♦	♦
Ensure data are accessible, discoverable, and usable (i.e., open data format to promote understanding, innovation, and personal and system responsibility. See Burwell, VanRoekel, Park, & Mancini, 2013.).	♦	♦	♦
Enable third-party providers access to data to support personalized learning, while also protecting students' privacy and FERPA rights.	♦		
The Best Technology Is Indentured to the Service of Decision Making			
Incorporate, but do not rely solely upon, comprehensive learner profiles and predictive analytics to provide adaptive learning and power customized learning paths for each student.		♦	♦
Ensure educators (and students when appropriate) understand the pedagogy, data, and decision-making opportunities in educational software.		♦	♦
Create funding mechanisms for districts and schools to encourage innovative uses of technology to support decision making at all levels.	♦		
Publish annual evidence-based digital "updates" on innovative personalized learning models, focusing on strengths and essential criteria.	♦	♦	

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