Using Technology to Personalize Learning in K–12 Schools

Authored by: SRI Education

November 2018

SRI Education™
A DIVISION OF SRI INTERNATIONAL

Suggested Citation

SRI International (2018). “Using Technology to Personalize Learning in K–12 Schools”. SRI International, Menlo Park, CA. Available from https://www.sri.com/work/publications/using-technology-personalize-learning-k-12-schools.

Contents

Illustration and Tables

Acknowledgments

This research brief was developed in 2014-15 by a project team at SRI with input from staff at the U.S. Department of Education's Office of Educational Technology. This work was funded in part with Federal funds from the U.S. Department of Education under contract number ED-04-CO-0040/TO10. The content of this report does not necessarily reflect the views or policies of the U.S. Department of Education nor does mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government.

Nicole Shechtman and Andrew Krumm of SRI International led report development and drafting. Contributing authors were Marie Bienkowski, Soren Rosier, and Linda Shear. Barbara Means, Marianne Bakia, and Robert Murphy, also of SRI, provided advice and insightful feedback on drafts. Vickie Watts provided administrative assistance. The report was edited by Mimi Campbell. Kate Borelli produced the layout. We thank Ruchi Bhanot, Savitha Moorthy, and Timothy Podkul for their contributions to data collection and analysis.*

The authors thank the following researchers for interviews: Vincent Aleven (Carnegie Mellon University), Roger Azevedo (North Carolina State University), Ryan Baker (Teachers College, Columbia University), Jose Blackorby (SRI International), Kevyn Collins-Thompson (University of Michigan), Carol Connor (Arizona State University), Chris Dede (Harvard University), Barry Fishman (University of Michigan), Julia Freeland (Clayton Christensen Institute), Richard Halverson (University of Wisconsin), Daniel Hickey (University of Indiana), Mizuiki Ito (University of California, Irvine), Kennneth Koedinger (Carnegie Mellon), Julie Marsh (University of Southern California), Taylor Martin (Utah State University), Timothy McKay (University of Michigan), William Penuel (University of Colorado), Kylie Peppler (University of Indiana), Jeremy Roschelle (SRI), Valerie Shute (Florida State University), Carol Tomlinson (University of Virginia), Candace Walkington (Southern Methodist University), Dylan Wiliam (Institute of Education, University of London), and Phil Winne (Simon Fraser University).
The authors also thank the educational leaders interviewed at the following organizations: Alpha Public Schools, Aspire Schools, Charleston County School District, Dysart Unified School District, Firstline, Galt Joint Union School District, KIPP-DC, Michigan Educational Authority, Nava Academy (Los Angeles), New Tech Network, Puget Sound Educational Service District, Rocketship Education, Summit Public Schools, Thrive Public Schools, USC Hybrid High School, Utica Community Schools, and Vail Arizona Unified School District.

The authors thank the leaders interviewed at the following technology providers: Achieve3000, Agilix, CFY/PowerMyLearning, Declara, DreamBox, Education Elements, eScholar, eSpark, Getting Smart, Goalbook, Gooru, Illuminate, Khan Academy, Knewton, and LearnSprout.

**All institutional affiliations are current as of June 2015.*

Executive Summary

Using technology to personalize learning has become a high-profile trend in K–12 education. Personalized learning—generally conceptualized as tailoring learning experiences to individual students' needs and interests—has been a centerpiece of education for students with disabilities for several decades. Now it is a term used widely to describe a variety of technologies, reform agendas, and instructional approaches for all student populations. Educators are looking to personalized learning approaches to move beyond one-size-fits-all schooling to new approaches that address both persistent and emerging educational challenges, such as achievement gaps and student disengagement. Educators are also seeking ways to keep up with the needs of a rapidly changing world in which student populations are increasingly diverse, workforce needs are shifting more toward 21st century competencies, and workers of tomorrow will need to take on more responsibility to manage their own lifelong learning and professional development.

A new generation of educational technologies is creating unprecedented opportunities for personalization. Technologies that can automatically adapt to students' learning needs are increasing in prevalence. A myriad of quality online educational materials make it possible for teachers and students to choose and follow individualized educational paths. Whereas these resources themselves may or may not offer personalized designs, their open availability is expanding many students' access to educational resources that can be more readily aligned with their interests and can be used anytime and anywhere.

Many schools, districts, and charter management organizations are making small and large-scale changes to promote personalized learning. They are adopting new technologies, expanding technological infrastructure, building teacher capacity, and in some cases reconceptualizing their models of schooling. Moreover, prominent funding agencies and institutions are building personalization into funding requirements and providing strong incentives to integrate personalized learning into proposed school and district reform designs. As these opportunities grow, a number of preexisting state and federal statutes protect students' and families' rights by governing practices concerning privacy and security of student data. Multiple federal laws also help guarantee equal access to educational resources and opportunities for all students.

While there is widespread excitement along with signs of promise for technology-enabled personalized learning, it is a newly emerging educational trend, and much work is still needed to design and implement approaches in ways that are supported by research and are in all students' best interests. Disparate perspectives exist on what constitutes personalized learning and how

best to support it; evidence on what works, for whom, and under what conditions is still emerging; policy makers wrestle with how to apportion resources to support personalized learning; districts and schools have new needs to build human capacity and technological infrastructure; technology developers are just beginning to leverage important technological advances; and researchers are working to understand design principles for personalized learning environments as well as gathering evidence on effectiveness.

Purpose of This Report

Given these emerging opportunities and challenges, this report is intended to support educators, education leaders, policy makers, technology developers, and researchers in becoming informed consumers and designers of new forms of technology-enabled personalized learning. Drawing on interviews with leaders in personalized learning research, practice, and technology, and informed by a survey of relevant research, policy documents, and white papers, this report discusses key aspects of personalized learning, how schools are organizing opportunities for personalized learning, and how technology can be used to enable personalized learning for a general K–12 student population. It culminates in recommendations to guide practitioners, policy makers, and researchers in designing, implementing, and enhancing personalized learning and building the foundations necessary for the success of this emerging approach.

Guiding Questions and Approach

This investigation of using technology to personalize learning in K–12 schools was organized around three clusters of guiding questions:

1. What is personalized learning? How does it work? What does current research suggest about its promise for education? What strategic supports are necessary for effective implementation?
2. How are schools creating technology-enabled personalized learning environments? What do they report as the essential elements of their models? What do practitioners and policy makers need to consider when transitioning to personalized learning in schools?
3. In what ways can technology foster personalized learning? What are some examples of these technologies, and how do they work? What are the current limitations of technology and potential for the future?

These questions were addressed during the period from late 2013 to mid 2014 through interviews with researchers, educators, and technology vendors, as well as a survey of pertinent research reports, policy documents, and white papers. Interviews were conducted with 24 researchers, 34 representatives of 17 schools and districts, and 19 representatives of technology vendors. Pertinent literature items were identified based on recommendations from researchers, searches on research topics gleaned from prior definitions of personalization, and the bibliographies of identified reports and researcher-nominated studies. Because few studies address the effects of personalized learning specifically, a noncomprehensive review focused on related topics that have more mature research bases such as individualizing instruction, interest-driven learning,

data-driven decision making and formative assessment, and adaptive software. The scope of this report encompasses personalized learning in formal K–12 general education learning environments where technology plays a central role. Although technology-enabled personalized learning is important in higher education and informal learning environments, these settings were not the focus of this report; however, many of the issues and solutions identified may apply to them. Also beyond the scope of this report were a specific focus on personalized instruction for students with disabilities and personalized learning approaches that do not rely on technology.

Defining Personalized Learning

The term *personalized learning* has become ubiquitous. It is sometimes used interchangeably with related concepts such as adaptive learning, competency-based learning, and differentiated instruction. For the purposes of this report, the following definition is used:

> *Personalized learning refers to instruction in which the objectives, pathways, and pace of learning experiences are optimized for each learner's needs, interests, and ongoing performance.*

Objectives refers to the particular learning goals a student is working toward; *pathways* refers to the learning activities, tools, presentation modalities, and resources the student is using to attain these objectives; and *pace* relates to the amount of time the student needs to attain mastery of these objectives. Each of these elements can be assigned to or chosen by students on the basis of measures of their needs, interests, or ongoing academic performance. Personalization thus involves tailoring multiple elements of instruction, stressing the importance of understanding each learner as an individual, and matching learning experiences to his or her needs and interests. Technology is typically a critical tool for enabling these processes.

Given this definition, the process of personalized learning can be characterized by a cycle of four processes: (1) engage, (2) measure, (3) interpret, and (4) adapt. Personalization involves students *engaging* in a learning experience of some kind, from which their individual needs, interests, and performance can be *measured*. After measures have been collected, they are *interpreted* relative to some set of standards or criteria. This interpretation is then used to inform specific *adaptations* of the learning experience that can differ across students in terms of objectives, pathways, and/or pace. Depending on the way the learning environment is configured and the role of technology, in a given setting such interpretations and adaptations can be made by technology itself, the teacher, or the student.

Privacy and Accessibility in Technology-Enabled Personalized Learning

With such a strong emphasis on the use of data and the reliance on technology for achieving core educational goals, discussions of technology-enabled personalized learning must include the protection of student privacy and accessibility for students with disabilities.

As a society, we have a responsibility to safeguard our children. Educators, technology developers, and researchers must be aware of laws and best practices that exist to keep children safe while using technology. In addition to a growing number of state and local statutes are four pertinent federal statutes on student privacy: the Family Educational Rights Privacy Act (FERPA), the Children's Online Privacy Protection Act (COPPA), the Protection of Pupil Rights Amendment (PPRA), and the National Research Act (NRA).

We also have a responsibility to ensure equal access to the educational benefits and opportunities afforded by technology and equal treatment in the use of the technology for all students, including those with disabilities. Multiple federal laws concern these rights. For example, the Americans with Disabilities Act of 1990 and Section 504 of the Rehabilitation Act of 1973 prohibit educational institutions from using any technology that is not fully accessible to students with disabilities unless those students are provided accommodations or modifications that permit them to receive all the educational opportunities and benefits provided by the technology in an equally timely, equally effective, and equally integrated manner with substantially equivalent ease of use. Additionally, Title VI of the Civil Rights Act of 1964 prohibits discrimination on the basis of race, color, or national origin.

Essential Elements of Technology-Enabled Personalized Learning Environments

Addressing the second research question, several recurring themes emerged from the interviews with educators about essential elements of their approaches to creating personalized learning environments with technology. No one school or district evidenced all these elements, and no element is intended to be enacted in isolation or assumed to be a required condition for personalized learning. Note that this list is not intended to be comprehensive. Moreover, as discussed throughout the report, currently little guidance exists from research about what constitutes effective practice for personalized learning, and these elements were not evaluated in relation to student outcomes or comprehensively in relation to educators' perceptions of success. As a complement to this report, recent case studies from Race to the Top – District participants highlight promising practices (U.S. Department of Education, 2014b). The recurrent themes were the following:

1. **Students are empowered to exercise personal agency and responsibility.** In many approaches, students may have the opportunity to choose many aspects of their learning objectives, pathways, and/or pace and be responsible for monitoring and assessing their own learning processes.

2. **Competency-based learning progressions.** Students are provided with the time and resources they need to master content at their own pace.

3. **Blended learning opportunities.** Educators blend modes of instruction by apportioning time between face-to-face and online instruction.

4. **Individual learning pathways.** Personalized learning plans may contain the academic goals that a student will focus on and provide guidelines for personalizing learning opportunities relative to objectives, pathways, and/or pace.

5. **Frequent, immediate feedback.** Assessment and feedback are critical to tailoring and include ongoing formative assessments, quizzes, and checks for understanding. These types of measures may or may not be embedded in technology and are typically complemented by traditional types of diagnostic and summative assessments.

6. **Culture of self-regulated learning.** Many personalization approaches that emphasize opportunities for students to exercise personal agency and responsibility in their own learning processes are also concerned with creating a culture in which students are supported in developing the academic mind-sets, learning strategies, and self-regulated learning behaviors necessary for productive empowerment.

7. **Strong teacher-student relationships.** Promoting strong teacher-student relationships helps teachers understand students' individual needs so a teacher can adapt instruction to those needs and promote a sense of belonging that can be critical to academic success.

8. **Engaged parents and guardians.** Parents and guardians can be active participants in tailoring by providing educators with information on the best learning environment for their sons and daughters and supporting personalized learning after school hours.

9. **Restructured roles for educators.** Roles for teachers generally shift to be less directive and didactic and more consistent with coaching and curating learning resources.

10. **Enhanced educator capacity.** Schools incorporate training to support teachers in using new approaches to understand individual students' learning needs, differentiate instruction, curate materials, manage class time, and cultivate student agency. Principals also need support as they enact new visions for their schools.

11. **Infrastructure and support.** Modifications may include acquisition of the devices students will use, broadband access, and tools for teachers; creating open physical spaces for blended learning in which students have the freedom to move among rotation stations; and extended school days, block scheduling, or year-round schooling. Data security and accessibility of technology for students with special needs and disabilities must also be key considerations.

12. **Strong educational leadership focused on technology-enabled personalized learning.** Many site-based leaders, such as school principals, assumed new responsibilities for implementing and sustaining complex visions of educational models that incorporate many of these elements (see U.S. Department of Education, 2014b).

Roles for Technology in Personalizing Learning in Schools

Within these new educational approaches, technology plays major roles in supporting personalized learning, which can be organized into the following three categories.

Automated adaptation of learning opportunities. Adaptive educational systems are perhaps the most popular and widely recognized types of technology supporting personalized learning. The defining feature of such systems is that one or more elements are modified in direct response to information collected about the learner on a continual basis. In schools, common adaptive educational systems are stand-alone software programs that teach the content of a single subject. For example, *cognitive tutors* are systems that provide the kinds of hints, prompts, and scaffolds that a human tutor would, informed by continual measurement of what students do and do not know. *Competency-based systems* support different pacing and scaffold students' developing content mastery. The design of adaptive learning systems is typically based on a theory of learning drawn from observations of how knowledge in a given content area is organized and interrelated, how typical learners engage with content, how expert tutors support the learning of typical students, and how expert teachers make instructional decisions.

Support for resource curation and management. Across the multiple activities, apps, instructional videos, educational games, and interactive websites that are available, teachers and students need support in finding the resources that meet diverse needs and interests. Technologies that support curating and managing resources are typically platforms that integrate free and fee-based educational resources into one unified log-in and delivery interface so that teachers or students can choose among them. Activities are typically delivered to students in the form of their own playlist. *Content curation systems* have underlying vetting and search processes for enabling teachers or students to find resources for a particular instructional need. *Learning resource platforms* provide centralized access to a more targeted set of content resources that can be customized by the school. In addition, *web-based repositories and communities* have been developed to help teachers find resources.

Support for using student data. Data can come from a variety of sources—for example, system log data from online systems, state assessments, district benchmark exams, measures of students' preferences and interests, and homework submissions. Some schools have adopted technologies that help to integrate data across multiple databases and digital learning environments and display those data for teachers, students, administrators, and parents. These enable personalization by supporting the interpretation of data necessary for adapting learning opportunities. Data displays and visualizations can also be integral to adaptive learning systems and content curation platforms by providing users (typically students) tailored recommendations and feedback on how well a student is progressing. Vendors should work with schools to provide assurances that the data will be kept securely and that privacy will be strictly protected, as required by FERPA, COPPA, and other relevant state or federal policies.

Exploring Potential Benefits of Technology-Enabled Personalized Learning

Researchers, educators, and technology developers expressed strong optimism about some of the potential benefits of these newly emerging technology-enabled personalized learning approaches. Aggregated across informants, the following potential outcomes were identified:

- **Enhanced learning, engagement, and equity for students**. These approaches have the potential to enhance learning by enabling students to learn faster, in greater depth, or with greater breadth across content areas; they may support engagement, persistence, or interest in learning; they may be a viable strategy for supporting equity, closing achievement gaps, or increasing retention and graduation rates. Realizing this potential equitably for all student populations, including students with disabilities, requires careful attention to issues of accessibility.

- **Enhanced supports for teachers**. These approaches have the potential to help teachers focus more effectively on how individual students are learning and how to support and accelerate their learning.

- **More supportive and equitable learning cultures and educational productivity in schools and districts**. Some approaches have the potential to produce broad school- or district-level cultural shifts, such as toward more rigorous standards for all students or to a greater emphasis on 21st century skills. Also, through practices that make better use of teacher and student time and increase the rate of student learning, personalized learning approaches also have the potential to improve educational productivity.

However, there is currently limited rigorous research that meets the procedures and standards of the What Works Clearinghouse for experimental or quasi-experimental designs (U.S. Department of Education, 2014c) to test intervention impacts, although many studies do align with newer methods for collecting evidence in technology-rich environments (U.S. Department of Education, 2013). In general, few interventions in the research literature are referred to by the labels of "personalization" or "personalized learning." However, studies from related topics point to the potential for personalized learning approaches and that personalized learning interventions warrant investment in rigorous field-based research to examine effectiveness and identify best practices.

Key Considerations for the Personalized Learning Conversation

Researchers, educators, and technology developers identified a set of important considerations in implementing technology-enabled personalized learning approaches. Aggregated across informants, the following themes were identified.

Operational challenges. Educators described many of the challenges they experienced when transitioning to personalized learning in their schools. Challenges foremost on their minds were supporting teachers' management of multiple changes at the same time, processes for setting individual learning goals for all students, processes for selecting the right individualized instructional resources, determining how to use data streaming in from multiple sources, having students manage using a variety of systems with multiple log-ins, ensuring that the technological infrastructure is adequate, bringing parents into the personalized learning process, and leveraging financial resources to support changing needs.

Limitations of technology. Informants indicated several limitations of currently available technologies that may need to be addressed in implementing personalized learning approaches. One is that the interpretation and use of data are limited by the quality and types of data

available, and the availability of data varies widely across technologies. Another is that content recommendation systems may have sophisticated search engines, but automating the match of materials to learner characteristics and needs is an unsolved problem. Also, best practices for the integration of data from multiple sources are still under development, and technology companies are still working on ways to make multiple sources of data truly understandable and actionable. Not all systems are adequately engaging for all students to ensure that blended learning approaches will work consistently, and there is still much work to be done to develop robust principles for how adaptations should be made in adaptive systems.

Need for strategic supports. Informants also identified several types of strategic supports that can facilitate effective implementation of personalized learning approaches. For example, many students may require extra time and individualized attention to learn—particularly those who tend to learn more slowly and could fall behind their classmates in a competency-based learning model. Further, students offered greater independence may at the same time need extra support in staying productive and pushing themselves to take on academic challenges. Educators also need to ensure that personalized learning approaches, which could potentially focus on rote learning and memorization, promote rigorous instruction and high-level thinking skills. As teachers reorganize their practice and classroom structures, instructional systems need to be carefully designed to optimize their use of time. In addition, educators need to make sure that personalized learning does not overemphasize technology-based learning and continues to leverage the learning and support that can come from teachers and peers.

Conclusions and Recommendations

Based on this survey of personalized learning approaches and the associated potential benefits and challenges, the following recommendations are intended to guide educators, policy makers, and researchers as they work to design, implement, and enhance personalized learning.

Recommendations for Educators

These recommendations are intended to promote the development of implementation models geared to maximize benefits for students, teachers, principals, and institutions while strategically addressing common challenges.[1]

1. **Learn from the agencies, organizations, and schools engaged in promoting personalizing learning using technology.** Chapter 5 provides a list of resources for gathering important information, including a pointer to recent in-depth case studies from Race to the Top – District schools (U.S. Department of Education, 2014b).

2. **Make informed decisions about technology to support personalized learning, and ensure that the necessary technology infrastructure will be available.** Chapter 5 includes a checklist of questions intended to help educational leaders refine a comprehensive vision of

[1] Educators must also be aware of their federal civil rights obligations to ensure equal access for all student populations, including students with disabilities.

their personalized learning approach and the role of technology in that vision, and to highlight important information to gather from technology vendors before selecting their products.

3. **Support educators in shifting roles and developing new capacities.** Personalized learning models require new teacher and principal roles, some that are unfamiliar and require new professional knowledge and supports. District and school site leaders should assess learning and staffing needs and plan accordingly. Teachers themselves need to be exposed to what it is like to be a learner within the personalized learning model, and they also need individualized professional supports as they transition into their new roles and capacities.

4. **Promote teaching practices and technologies that support students' productive engagement, self-regulated learning, and development of conceptual understanding.** When technology is a major aspect of the learning environment, educators need to be particularly attentive to students' productive engagement and appropriate self-regulation of their learning. Educators seeking to support students' conceptual understanding, creativity, problem solving, and communication skills should also make sure that the instructional systems they adopt support these kinds of learning.

5. **Consider implementing changes that might be necessary to address challenges of working with students learning at different paces.** Some schools are accommodating different paces, especially for students who struggle and need to catch up, by lengthening the school day, increasing the number of school days per year, providing support time on the weekends, or moving to a year-round schedule. Additional supports are likely to be necessary for students with disabilities.

6. **Consider how leaders in all parts of the system can engage in continuous improvement efforts.** With the introduction of any initiative in schools, teachers and school leaders should expect to go through multiple cycles of program design, implementation, evaluation, and refinement.

Recommendations for Policy Makers

These recommendations are intended to address some high-level policy issues and some of the ways that policy makers can reduce barriers and promote personalized learning in schools.[2]

1. **Provide financial resources for start-up costs for the transition to personalized learning and ongoing continuous evaluation and improvement.** Policy makers can make strong contributions to the implementation of these models by ensuring that schools have the resources needed for technology, data warehousing, professional development, facilities, and evaluation.
2. **Promote investment in high-quality, effective, integrated, and secure technology systems to support personalized learning.** Policy makers can create incentives for schools, researchers, and technology developers to create and implement high-quality personalized

[2] State and local policy makers, in considering changes that reduce barriers and promote personalized learning that might impact the use of federal grant funds, will have to ensure continued compliance with federal requirements.

learning supports. In its supplemental priorities for discretionary grant programs, the Department already emphasizes programs that promote personalized learning (U.S. Department of Education, 2014a, 79 FR 73425). Policy makers can also play an instrumental role in developing standards for technology vendors and making data sets accessible, interoperable, and linkable in compliance with state and federal laws for student privacy and data security.

3. **Support more flexible accountability structures compatible with competency-based learning models and innovations in educational approaches.** Policy makers can establish structures that allow for the flexibility needed to empower struggling students, promote new teacher roles, and make provisions for schools to innovate. Approaches may include modifying seat-time requirements to support competency-based learning.

Recommendations for Researchers

These recommendations are intended for researchers who want to advance the knowledge base for supporting personalized learning models.

1. **Conduct rigorous field-based research to examine the impacts of personalized learning interventions and identify promising practices.** Researchers need to examine the impacts of personalized learning interventions on a wide range of potential outcomes for students and educators, as well as to identify specific practices for implementing evidence-based personalized learning. There is a strong need for rigorous field-based randomized experiments and quasi-experimental designs that meet the standards for What Works Clearinghouse (U.S. Department of Education, 2014c) as well as more agile approaches that leverage data-rich technologies (U.S. Department of Education, 2013).
2. **Develop research-based frameworks to clarify and unify concepts that structure and inform personalized learning models.** Researchers can play an instrumental role in teasing apart conceptual distinctions that are critical to practice and construct consolidated frameworks and models to inform evidence-based practice.
3. **Build and expand the science behind learning trajectories, adaptation of learning experiences, assessment during learning processes, and provision of actionable data for teachers and students.** A deeper understanding of these critical components of learning will promote greater success in the design and implementation of technologies and instructional models intended to support personalization. Special attention should be given to the needs of students with disabilities.
4. **Translate findings and provide research-based guidance on how to implement effective personalized learning models with fidelity and overcome potential implementation challenges.** Researchers in universities and nonprofit organizations are well positioned to explore the issues identified in the implementation of personalized learning to help others adopt effective models with fidelity. This inquiry should also attend to potential drawbacks and ways to implement strategic supports for effective implementation.

1. Introduction

We live in a time of increasing personalization. This is particularly visible online—Internet searches, product recommendations, and advertisements are all routinely tailored to each unique user. In health care, treatment approaches can be customized to individuals, and tailored health communications have demonstrated strong positive effects on complicated outcomes like smoking cessation (Strecher et al., 1994). Personalization is supporting new visions for education as well. Many are seeking to move beyond traditional one-size-fits-all approaches to schooling in efforts to address persistent educational challenges. The emergence of a new generation of educational technologies is at the center of multiple approaches to personalization, providing new possibilities as well as new challenges.

The Emergence of Technology-Enabled Personalized Learning

Personalized learning—generally conceptualized as tailoring learning experiences to individual students' needs and interests—is not new. Many of the driving ideas for personalization have been discussed and practiced for decades and even centuries. The ideas of personalization can be found in the writings of 18th century philosopher Rousseau as well as in those of early 20th century educational leaders such as Dewey and Montessori. Personalization has also been the fundamental requirement of the Individuals with Disabilities Act (IDEA) for nearly 40 years, with provisions for the individualized education program for students with disabilities.

Now, with the convergence of evolving societal needs, policy conditions, and the opportunities afforded by new technologies, technology-enabled personalized learning for all student populations has become a high-profile trend in K–12 education. As many schools transition to new content standards (e.g., Common Core State Standards and Next Generation Science Standards), leaders are working to identify new instructional approaches that will ensure that all students meet the rigorous expectations. Educators are also seeking new ways to move beyond traditional learning approaches to address such persistent challenges as ongoing achievement gaps, student disengagement, and attending to the broad diversity in students' learning needs and interests. Educators must also keep up with the needs of a rapidly changing world in which many workforce sectors are demanding new skills, increasing specialization, and placing more responsibility on individuals to manage their own lifelong learning and professional development. Stakeholders in education are looking to personalized learning approaches to help address these challenges.

This focus is supported by a new generation of educational technologies that are creating unprecedented opportunities for personalization. Some examples are:

- **Availability of new approaches for collecting and analyzing data.** Growing technical capabilities are creating opportunities for data-driven personalization in ways never before possible. For example, well-instrumented digital learning systems can capture student activities at the keystroke level and, when combined with advances in statistical and data mining approaches, can be used to diagnose misconceptions and recommend individualized instructional content (U.S. Department of Education, 2012a, 2013). As these opportunities grow, a number of state and federal statutes protect students' and families' rights by governing practices concerning privacy and security of student data.
- **Availability of high-quality digital learning materials.** Some students today are able to choose and follow their own educational path using a wide range of quality online learning materials. Massive online open courses (MOOCs) and other free online educational materials increase many students' access to high-quality content on a myriad of topics. Although these resources themselves may or may not have personalized designs, their open availability is increasing students' access and the potential for students to follow their interests. At the same time, this brings to the forefront the growing need to address issues of accessibility, for example, for students who are visually impaired. Approaches such as Universal Design for Learning (see http://cast.org/udl) are becoming increasingly important.
- **Ubiquity of mobile devices and increased connectivity.** The ubiquity of Internet-connected phones and tablets has provided many learners the opportunity to connect anywhere, anytime to quality learning materials. Just as mobile connectivity has increased through devices and service providers, wired connections in schools and homes have increased in bandwidth, providing opportunities to connect to and engage with rich media (U.S. Department of Education, 2014d).

Many schools, districts, and charter management organizations are making small and large-scale changes to promote personalized learning. They are adopting new technologies, expanding technological infrastructure, building teacher capacity, and in some cases reconceptualizing their models of schooling. The U.S. Department of Education's Race to the Top – District program provided approximately $500 million from its 2012 and 2013 competitions to support districts in developing personalized teaching and learning approaches. Many philanthropic organizations, such as the Bill & Melinda Gates Foundation, are also making investments in schools and districts intended to promote personalized school models. Programs such as these have been providing strong incentives for educational leaders to integrate personalized learning into school and district reform efforts.

While there is widespread excitement along with signs of promise for technology-enabled personalized learning, it is a newly emerging educational trend, and much work is still needed to design and implement approaches in ways that are supported by research and are in all students' best interests. Disparate perspectives exist on what constitutes personalized learning is and how best to support it; evidence on what works, for whom, and under what conditions is still emerging; policy makers wrestle with how to apportion resources to support personalized learning; districts and schools have new needs to build human capacity and technological infrastructure; technology developers are just beginning to leverage important technological

advances; and researchers are working to understand design principles for personalized learning environments as well as gathering evidence on effectiveness.

Purpose of This Report

Given these emerging opportunities and challenges, this report is intended to support educators, education leaders, policy makers, technology developers, and researchers in becoming informed consumers and designers of new forms of technology-enabled personalized learning. Drawing on interviews with leaders in personalized learning research, practice, and technology, and informed by a survey of relevant research, policy documents, and white papers, this report discusses key aspects of personalized learning, how schools are organizing opportunities for personalized learning, and how technology can be used to enable personalized learning for a general K–12 student population. It culminates in recommendations to guide practitioners, policy makers, and researchers in designing, implementing, and enhancing personalized learning and building the foundations necessary for the success of this emerging approach.

Guiding Questions and Approach

This investigation of using technology to personalize learning in K–12 schools was organized around three clusters of guiding questions:

1. What is personalized learning? How does it work? What does current research suggest about its promise for education? What strategic supports are necessary for effective implementation?
2. How are schools creating technology-enabled personalized learning environments? What do they report as the essential elements of their models? What do practitioners and policy makers need to consider when transitioning to personalized learning in schools?
3. In what ways can technology foster personalized learning? What are some examples of these technologies, and how do they work? What are the current limitations of technology and potential for the future?

These questions were addressed by identifying themes in the complementary approaches of interviews with expert researchers, educators, and technology vendors, and a survey of pertinent research reports, policy documents, and white papers. Researcher informants were identified who had publication records addressing topics relevant to technology-enabled personalized learning, as highlighted in prior reports released by the U.S. Department of Education (2010b, 2012a, 2013). These topics included data-driven decision making, educational data mining/learning analytics, and technology use in schools. Educator informants were teachers and administrators in districts and CMOs nominated by experts as doing important and innovative work. Technology vendor informants were leaders in companies that provide widely used educational technologies for supporting personalized learning in schools. In total, interviews were conducted with 24 researchers, 34 representatives of 17 schools and districts, and 19 representatives of technology vendors. A semistructured interview protocol was used and tailored for each interview to the specific expertise of the individual informant. Most interviews were conducted

by phone, with the exception of a handful of site visits to interview educators where some informants were interviewed together as a focus group. Responses from each interview were coded thematically with respect to the guiding questions.

Pertinent research reports, policy documents, and white papers were identified based on recommendations from the expert informants, searches on research topics gleaned from prior definitions of personalization, and the bibliographies of identified reports and researcher-nominated studies. Many of these documents were used to complement interviews and provide further depth and context for major themes identified. Along with providing depth and context to developing themes, studies were also sought that demonstrated the effectiveness of personalized learning interventions. Few research studies address the effects of personalized learning specifically; a search of education databases using such search terms as personalization and personalized learning led to articles and reports that described the potential of personalized learning rather than well-defined interventions associated with personalized learning. In consultation with the expert informants, this search was expanded to incorporate a noncomprehensive review of closely related topics with more mature research bases such as individualizing instruction, interest-driven learning, data-driven decision making and formative assessment, and adaptive software.

The scope of this report encompasses personalized learning in formal K–12 general education environments. Although personalization in higher education and informal learning environments is not the focus of this report, many of the concepts outlined here can apply in those settings as well. Likewise, there is an extensive research and knowledge base on personalized instruction for students with disabilities, but that also was outside the scope of this report (see below for additional information). Finally, this report addresses personalized learning approaches that highlighted the role of technology. Some forms of personalized learning can be accomplished without technology (e.g., see Darling-Hammond & Friedlaender, 2008), but this report concerns personalization supported by current or emerging technologies.

Ensuring Equal Access to Educational Benefits and Opportunities

While not a specific focus of this report, it is important to raise awareness of the multiple federal laws that help guarantee equal access to the educational benefits and opportunities afforded by technology and equal treatment in the use of the technology for all students, including students with disabilities. For example, the Americans with Disabilities Act of 1990 and Section 504 of the Rehabilitation Act of 1973 prohibit educational institutions from using any technology that is not fully accessible to students with disabilities unless those students are provided accommodations or modifications that permit them to receive all the educational opportunities and benefits provided by the technology in an equally timely, equally effective, and equally integrated manner with substantially equivalent ease of use. Additionally, Title VI of the Civil Rights Act of 1964 prohibits discrimination on the basis of race, color, or national origin. To comply with the many statutes in place, it is critical that educators, educational leaders, policy makers, technology developers, and researchers provide personalized learning opportunities in a manner that does not discriminate, that is accessible, and that does not widen the digital divide between those who have the ability to avail themselves of new innovations and those who do not.[3]

[3] For further information on schools' federal civil rights obligations concerning emerging technologies and students with disabilities, please see the June 20, 2010, "Dear Colleague Letter" from Russlynn Ali, Assistant Secretary for Civil Rights, U.S. Department of Education, and Thomas E. Perez, Assistant Attorney General, Civil Rights Division, U.S. Department of Justice, on accessible electronic book readers for students with disabilities (available at http://www2.ed.gov/about/offices/list/ocr/letters/colleague-20100629.html). See, in addition, the May 26, 2011, "Dear Colleague Letters" with attached Frequently Asked Questions document from Assistant Secretary for Civil Rights Ali, elaborating on the June 20, 2010, letter and addressing schools' use of electronic book readers and other emerging technologies in compliance with civil rights laws that prohibit discrimination on the basis of disability (available at http://www2.ed.gov/about/offices/list/ocr/letters/colleague-201105-ese.html, http://www2.ed.gov/about/offices/list/ocr/letters/colleague-201105-pse.html, http://www2.ed.gov/about/offices/list/ocr/docs/dcl-ebook-faq-201105.html).

2. Personalized Learning 101

This chapter addresses the following questions: *What is personalized learning? How does it work? What does current research suggest about its promise for education? What strategic supports are necessary for effective implementation?* Answers to these questions are drawn from interviews with 24 researchers in universities and nonprofit research institutes and a review of current literature.

Definition of Personalized Learning

The term *personalized learning* has become ubiquitous. It is sometimes used interchangeably with related concepts such as adaptive learning, competency-based learning, and differentiated instruction. For the purposes of this report, the following definition is used:

> *Personalized learning refers to instruction in which the objectives, pathways, and pace of learning experiences are optimized for each individual learner's needs, interests, and ongoing performance.*

This definition builds off the definition in the *National Education Technology Plan* (NETP) (U.S. Department of Education, 2010), as well as the Department's supplemental priorities and definitions for discretionary grant programs (U.S. Department of Education, 2014, 79 FR 73425). *Objectives* refers to the particular learning goals a student is working toward; *pathways* refers to the learning activities, tools, presentation modalities, and resources the student is using to attain these objectives; and *pace* relates to the amount of time the student needs to attain mastery of these objectives. Each of these elements can be assigned to or chosen by students on the basis of measures of their needs, interests, and ongoing academic performance. Personalization thus involves tailoring multiple elements of instruction, stressing the importance of understanding each learner as an individual, and matching learning experiences to his or her needs and interests. Technology is a critical tool for enabling these processes.

Other Definitions and Conceptualizations of Personalized Learning

Over the last several years, thought leaders from research, practice, and policy have been developing rich conceptualizations of what technology-supported personalized learning does,

can, or should look like in practice. This section presents several prominent perspectives. Across these perspectives, tailoring the objectives, pathways, and pace of instruction is critical. Many perspectives highlight other complementary factors that can be important, such as interpersonal relationships, pedagogies that leverage learning sciences research, and school contextual factors. The following is a description of critical elements of tailoring and complementary factors across multiple perspectives.

Graf and Kinshuk (2012), in their entry in the *Encyclopedia of the Sciences of Learning*, defined the general term of "personalized learning" as follows:

> Personalized learning means tailoring education to learners' current situation, characteristics, and needs in order to help learners to achieve the best possible learning progress and outcomes. Personalized learning can appear on different levels of education, including personalizing curriculums, courses, learning material, learning activities, and other learning support. Through personalized learning, each learner is provided with education that is tailored to his/her individual characteristics and needs and learns in a way that is most suitable for him/her, resulting in different learning experiences for each learner. (p. 2592)

Patrick, Kennedy, & Powell (2013), in their report for practitioner and technology developer audiences, sponsored by the International Association for K-12 Online Learning (iNACOL), defined "personalization" as follows:

> [Personalization 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. (p. 4)

These authors also make explicit ties to the "How People Learn" framework (National Research Council, 2001), emphasizing the need to use learning sciences principles to guide the design of personalized learning environments. They highlight 10 essential components:

> (1) student agency (student has voice and choice on level of standards/lesson and some control over how they learn); (2) differentiated instruction; (3) immediate instructional interventions and supports for each student is on-demand, when needed; (4) flexible pacing; (5) individual student profiles (personalized learning plan); (6) deeper learning and problem solving to develop meaning; (7) frequent feedback from instructors and peers; (8) standards-based, world-class knowledge and skills; (9) anywhere, any time learning can occur; (10) performance-based assessments, project-based learning, portfolios, etc. (p. 6).

In addition, the authors emphasize the importance of interpersonal relationships with other students and the teacher, collaboration, and sense of community.

The Bill & Melinda Gates Foundation, as part of its work in promoting college readiness, has been investing in initiatives to drive the development of technology-supported personalized learning models in schools and districts (Childress, 2014). The foundation's conceptualization of

personalized learning also highlights tailoring of learning experiences while emphasizing the importance of interpersonal relationships:

> By personalized learning, we simply mean that student learning experiences—what they learn, and how, when, and where they learn it—are tailored to their individual needs, skills, and interests, and that their school enables them to take ownership of their learning. Although where, how, and when they learn might vary according to their needs, students also develop deep connections to each other and their teachers and other adults. … Personalized learning challenges traditional school design by moving away from a teacher leading the whole class in a common lesson. Instead, each student can follow an optimal learning path and pace through a mix of instructional methods, including individual and small-group time with teachers, group projects, and instructional software. (Childress & Benson, 2014, p. 34)

CFY, a national nonprofit organization helping stakeholders integrate technology into learning opportunities for students, outlined two cycles of learning, one of which foregrounds the importance of personalization:

> "1. The Personalized Instruction cycle. Personalized instruction can best be thought of as a cycle in which student assessment data informs the selection of a set of activities for each student from a vast array of choices, then instruction is delivered through a number of modalities, then student learning is assessed, and then that assessment data is used to again inform the selection of a new set of activities for each student, and so on as the loop repeats.
> "2. The Student-driven Learning cycle. In the student-driven learning cycle, students drive their own learning at their own pace, self-assess, receive immediate feedback, and try again. The topics students choose to pursue may be something they are struggling with in school or something they are exploring based on their own interests." (CFY, n.d.)

CFY's approach also highlights how each of these cycles can take on different levels of prominence as students mature. In the early grades, for example, personalized instruction may be directly supported and managed by educators. As students gain maturity, the agency of the matching of learning experiences can move from educator to the student as he or she develops the ability to self-regulate and support his or her own learning.

The Software and Information Industry Association (SIIA) framed "technology-enabled personalized learning" as a systemic reform movement. It held two meetings with expert stakeholders to define and articulate key elements (Wolf, 2010; Wolf & Schneiderman, 2014):

> First, today's industrial-age, assembly-line educational model—based on fixed time, place, curriculum and pace—is insufficient in today's society and knowledge-based economy. Our education system must be fundamentally reengineered from a mass production teaching model to a student-centered, customized learning model to address both the diversity of students' backgrounds

> and needs as well as our higher expectations for students. (Wolf & Schneiderman, 2014, p. 2)

This report also described five essential elements of personalization:

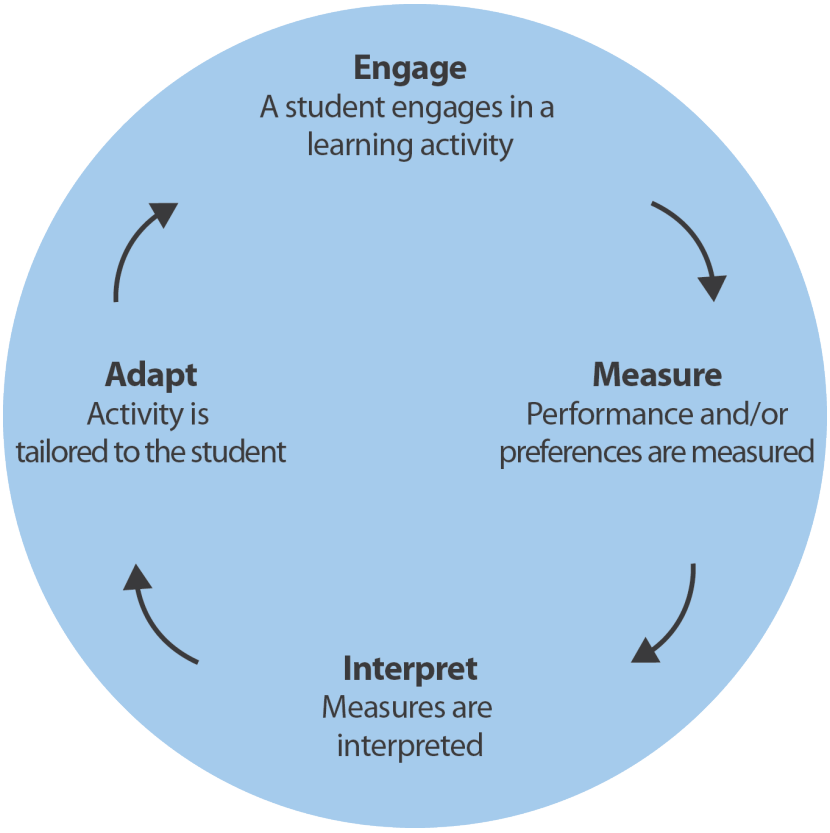
> (1) flexible, anytime, everywhere learning; (2) redefine teacher role and expand 'teacher'; (3) project-based, authentic learning; (4) student-driven learning path; and (5) mastery/competency-based progress/pace. (p. 4).

Each perspective incorporates tailoring, which, like a tailor's process in fitting a garment, involves taking measurements, becoming knowledgeable about preferences, and using that information to fit that particular person. In the educational context, tailoring relies on assessments and fitting instruction to the individual learner. Each perspective also addresses how to enhance learning opportunities for students by changing the ways they connect with teachers, content, and peers. While there is clearly diversity in the definitions and conceptualizations of personalized learning, the essential elements of personalized learning involve matching learning experiences to a student based on his or her learning needs, capacities, and interests.

An Overview of How Personalized Learning Works

How does this tailoring process work? Put simply, in order to match a learning experience, students' needs, interests, and ongoing performance must be measured and then acted on. Personalization, therefore, is propelled by the use of data about a student to customize learning experiences. Figure 1 shows the "tailoring cycle," which includes four basic processes. Customization can begin when a student *engages* in a learning activity and performance and/or preferences are *measured*. Once collected, the data need to be *interpreted* and then acted on to *adapt* to the student. These four processes can be identified across a diversity of learning environments, from adaptive software to whole-school models organized for personalization. What differs across the various kinds of learning environments is the kinds of measures used, the specific ways the measures are interpreted, and the nature of the adaptations that are made—the processes stay the same, but what goes into them varies. The following discusses each process in more detail.

Figure 1. Four processes of the tailoring cycle



1. **Engage.** The process of personalization often begins with a student engaging in a learning activity. Decisions about how to adapt learning opportunities are based on data, and some of the best opportunities to collect data are those in which students are actively engaged in a learning activity. The type of activity that students partake in will shape the type of data that can be collected. For example, as students participate in a small-group activity, the teacher may be able to ask them targeted open-ended probing questions that will help in tailoring upcoming components of the lesson. For digital learning environments, researchers in learning analytics and educational data mining are developing methods to collect more and different types of data as students engage in learning activities (U.S. Department of Education, 2012a, 2013). Shute and Ventura (2013), for example, observed that data collected from gaming environments can be used in real time to lead to important insights into students' knowledge, skills, and abilities. While the demarcation between learning activities and data collection is blurring in many educational settings, most classroom learning activities remain separated from formal assessment.

2. **Measure**. Depending on the learning activity, different characteristics of students may be measured. For example, measures may address what students know, their interests, their preferences, or their mastery of particular learning objectives. It is important that the tools and techniques be sensitive enough to detect changes as well as predict potential outcomes. The most common type of measurements used for making instructional decisions are based

on what students know, such as quizzes and tests (U.S. Department of Education, 2009a); however, measures can also examine students' preferences and interests. Important to measuring before, during, and after a learning activity is clarifying the types of measures to be used, what they are measuring, the purposes the resulting data will be put to, and whether the measurement is occurring in an obtrusive or unobtrusive ways.

3. **Interpret.** Once measures have been made, they need to be interpreted. Interpretation involves attending to some data over others, simplifying, and connecting different patterns to potential instructional adaptations (Coburn & Turner, 2011). Not all measures are equally meaningful to all potential instructional decisions. In the case of intelligent tutoring systems, for example, how a student performed on a recent problem informs an adaptation more than his or her performance on an assessment from the beginning of the school year. Interpretation is done by focusing on some data over others through the frames of reference, tools, or supports used to analyze data. These frames, tools, and supports filter information, structure comparisons, and bring to the surface categorical or qualitative differences among students (Spillane & Meile, 2007). As information is made sense of, it may be linked to potential instructional adaptations, and the types of adaptations that are possible will shape how data will be interpreted.
4. **Adapt.** Adaptations can be large or small and may be implemented by a technology or by a teacher. Students, too, can make adaptions for themselves based on data on their performance and interpretations relative to a self-selected goal. Means, Bakia, and Murphy (2014) organized types of adaptions as follows, which are consistent with the definition of personalized learning above focused on tailoring with respect to objectives, pathways, and/or pace:

    - pacing/time to learn (i.e., self-paced learning);
    - learning objectives (i.e., let learners choose their course of study);
    - content choices for specified learning objectives (e.g., opportunities to choose content to match learner background or interests while working on the same skills or concepts);
    - content complexity or difficulty level;
    - pedagogy (e.g., a tutorial versus learn by doing);
    - degree of learner control (e.g., fixed path through the content for some students while others get to choose their own learning sequence);
    - types of scaffolding (e.g., hints suggesting what a learner might review versus providing the prerequisite piece of knowledge);
    - nature and timing of feedback (e.g., information on whether the response was right or wrong versus information on what the learner might do to solve future such problems correctly) (p. 32).

These processes are portrayed as a cycle because they can occur in a continuous and ongoing manner. Once an adaptation is made and students take on their tailored learning experience, opportunities can continue to arise to hone instruction to individuals' evolving needs.

No matter how they are implemented, tailoring cycles are essential to technology-enabled personalized learning. Chapter 3 discusses tailoring cycles in the context of complex personalized learning environments, and Chapter 4 delves more deeply into the roles that technology can play in supporting tailoring cycles.

Student Data and Privacy in Technology-Enabled Personalized Learning

The reliance on data in these approaches requires careful attention to the fact that as a society, we have a responsibility to safeguard our children, recognize their vulnerability, and vigorously protect their privacy. Educators, technology developers, and researchers must be aware of how data privacy, confidentiality, and security practices affect students and of the privacy laws and best practices that exist to keep children safe while using innovative technology services. Educators in schools must understand what data from which providers they have access to and what their roles as educators are in safeguarding and providing access to various types of data. Technology developers need to understand what data they have access to and with whom they can share it. Researchers, while often working in accordance with Institutional Review Boards and human subjects research standards, must also be aware of legal constraints governing data access and security. Across constituencies, federal and state statutes are in place that provide protections for students' data and privacy. In addition to a growing number of state and local statutes that must be followed are four applicable federal statutes on student privacy pertinent to technology-enabled personalized learning: FERPA, COPPA, PPRA, and NRA.

The intent of these statutes is to protect students and student privacy. As multiple constituencies seek to engage further in research on personalization, these laws define appropriate practice. The U.S. Department of Education has established a Privacy Technical Assistance Center (https://studentprivacy.ed.gov/) website as a one-stop resource for education stakeholders to learn about data privacy, confidentiality, and security practices related to student-level longitudinal data systems and other uses of student data.

Exploring Potential Benefits of Technology-Enabled Personalized Learning

Researchers, educators, and technology developers expressed strong optimism about some of the potential benefits of newly emerging technology-enabled personalized learning approaches. Aggregated across informants, the following potential outcomes were identified:

- **Enhanced learning, engagement, and equity for students**. Personalized learning has the potential to enhance learning by enabling students to learn faster, in greater depth within a content area, or with greater breadth across content areas. Personalized learning may be a viable strategy for supporting equity, closing achievement gaps, or increasing retention and graduation rates. Some personalized learning environments are designed with the intention of increasing engagement, persistence, or interest in the short term within particular learning activities, whereas other approaches are designed more to sustain engagement over the long term, for example, targeting successful completion of high school and building the knowledge and skill base for college readiness. Realizing this potential equitably for all student populations, including students with disabilities, requires careful attention to issues of accessibility.

- **Enhanced supports for teachers**. These approaches have the potential to help teachers focus more effectively on how individual students are learning and how to support and accelerate their learning. Technologies can enhance teachers' practice in all aspects of the tailoring cycle, providing a multitude of resources, data, and ways of adapting instruction. In blended learning models, students' independent use of high-quality technologies can also free teachers to focus more intensively on providing differentiated support for individuals and groups.

- **More supportive and equitable learning cultures and educational productivity in schools and districts**. Some approaches have the potential to produce broad school- or district-level cultural shifts. For example, the vision of personalized learning can help facilitate larger district-level changes, such as shifting toward more rigorous standards for all students or to a greater emphasis on 21st century skills (U.S. Department of Education, 2014b). Moreover, through practices that make better use of teacher and student time and increase the rate of student learning, personalized learning approaches have the potential to improve educational productivity, the ratio between costs and outcomes (U.S. Department of Education, 2012b).

In light of this optimism, an important question is: are there empirical supports for the benefits of personalization? Research on the effects of personalization on learning per se is sparse, most likely because of the lack of a clear definition for personalized learning. In general, few interventions in the research literature are referred to by the labels of "personalization" or "personalized learning." However, in consultation with researchers, a number of closely related topics were identified that have more mature research bases. Presented here are highlights from a noncomprehensive review of these areas of research suggesting promise for personalized learning approaches.

- **Individualized instruction.** The premise of individualizing instruction is similar to that of personalization: Students have different abilities and will respond in unique ways to instructional opportunities (Tomlinson et al., 2003). One example of research on individualized instruction with technology is that of Connor et al. (2009). These researchers sought to optimize reading instruction by developing an online tool for teachers, along with professional development in how to use the tool, that collected data on various measures of their students' literacy abilities and provided direct input into instructional decisions about assigning individualized activities. The researchers found that teachers who were provided with this tool and the professional development had greater increases in their students' learning relative to those in classrooms that did not use the instructional decision-making tool. This research illustrates how digital tools can be used to support teachers in individualizing instruction and the potential benefits to learning when students receive more individualized instruction.
- **Interest-driven learning.** In interest-driven learning, learners pursue their passions and interests (Ito et al., 2013). Often studied in environments outside school, interest-driven learning has been linked to increased learner attention, motivation, and achievement (e.g., Cordova & Lepper, 1996; Hidi & Harackiewicz, 2000). Although interest-driven learning can be challenging to enact in formal school environments in which there is often incongruity between a student's interests and the goals of schooling (e.g., see Collins & Halverson, 2009; Hidi & Renninger, 2006), many researchers are beginning to make progress in this area. Walkington, Petrosino, & Sherman (2013), for example, implemented an interest-driven online learning platform for mathematics. They examined lessons about formal algebraic expressions in which story problems were customized to students' interests based on results from a survey. The researchers found that tailoring these learning experiences to students' interests had a positive impact on learning. Other researchers have had similar positive results in interest-driven online learning environments (e.g., Heilman et al., 2010; VanLehn, 2011).
- **Data-driven decision making and formative assessment.** A critical driver of personalization is the collection and interpretation of data. Research over decades has examined how data can be used to support instructional decision making (Piety, 2013). Growing evidence also illustrates how data from formative assessments can be used to modify instruction with attendant increases in student learning (e.g., Black & Wiliam, 1998; Young & Kim, 2010). Coburn and Turner (2011) described how under some conditions data can be used to better understand students and lead to more tailored learning opportunities. Both adaptive software and whole-school models organized for data-driven decision making (U.S. Department of Education, 2009a) facilitate processes parallel to those key to personalized learning—engage, collect, interpret, and adapt.
- **Adaptive software.** Multiple studies have documented the learning benefits of using adaptive software, with several recent reports noting that one form, intelligent tutoring software, can be as effective as one-on-one human tutoring (e.g., Natriello, 2013; VanLehn, 2011). Rigorous designs testing the effectiveness of such systems are becoming more common. For example, two adaptive systems for mathematics—Cognitive Tutor® and DreamBox® Learning—have been subjected to randomized experiments that demonstrated some effectiveness at different grade levels. Although there are still open questions about effectiveness across contexts, findings suggest that adaptive software with well-defined

student models, knowledge tracing, and detailed hint, help, and feedback support can compare favorably with human tutoring and surpass nontutored learning conditions.

While multiple research bases suggest promise for personalized learning approaches, there is still much work to be done to develop a research base for technology-enabled personalized learning. Among the research studies already available, there remains a need to unify these areas conceptually. There is also a strong need for rigorous field-based randomized experiments and quasi-experimental designs that meet the standards for What Works Clearinghouse (U.S. Department of Education, 2014c) and for additional complementary research that relies on newer methods for collecting evidence in technology-rich environments (U.S. Department of Education, 2013). Also of particular note is the lack of empirically supported teaching strategies that would promote effective personalized learning and training approaches that would promote adequate implementation of these strategies. For instance, in order for teachers to make effective use of data, they must be able to identify appropriate and psychometrically strong diagnostic tools to assess student learning needs, accurately interpret data from these tools, decide the instructional strategy that best addresses those identified learning needs (in relation to target student outcomes), and implement those strategies with adequate fidelity. Consensus on what these skills should look like across student populations and how to develop these skills in instructional personnel are limited. Furthermore, psychometrically strong measures designed to guide instructional decision making by providing specific, concrete suggestions on next steps in teaching are also limited.

The Need for Strategic Supports for Effective Implementation of Personalized Learning

Expert informants also pointed to potential risks of technology-enabled personalized learning implemented ineffectively and the need for strategic supports. The following types of supports were discussed in many interviews and aggregated across informants.

- **Many students may require extra time and individualized attention to learn.** Without careful planning and monitoring, personalized learning can potentially put lower achieving students at greater disadvantage. For example, students who are fast learners can cover much more content within the standard instructional time, but slower learners, required to demonstrate mastery before moving to new content, often need considerably more time than is usually allotted to work through the whole curriculum. Competency-based learning can also lead struggling students to repeat some material multiple times and fall behind their peers in curriculum coverage. In general, when students are required to demonstrate mastery before moving to new content, some will need considerably more time than is usually allotted to work through a curriculum. This may be particularly important for students with disabilities. For effective implementation, educators must consider how additional supports, such as extra time and individualized attention from teachers, can be given to those students who need them.

- **Students offered greater independence may need extra support in staying productive and taking on academic challenges.** In an effort to provide students with opportunities to exercise personal agency and responsibility, it is possible to provide too much choice.

Students may not have adequate foresight or maturity to know what learning objectives or pathways will provide the best future outcomes. They may not have sufficient self-regulation skills or interest in taking ownership of their own learning. Also, when teachers set up students to work independently on computers, the students might be unproductive and get off task (e.g., play games). Furthermore, although tailoring instruction to individual students' strengths can support engagement, individualization that overemphasizes strengths and ignores weaknesses could keep students from being challenged in ways that would have helped them grow. Educators must consider how choice, agency, and independence can be supported with appropriate guidance.

- **Educators need to ensure that personalized learning approaches promote rigorous instruction and high-level thinking skills.** The mastery learning approaches of computer-assisted instruction that were the forerunners of today's personalized learning systems emphasized behavioral skills and discrete knowledge elements. It remains easiest to assess students' competency with respect to these kinds of learning objectives and hence to build personalized learning systems around rote learning and memorization. Educators need to consider how personalized learning can include tasks that support the development of high-level thinking skills such as conceptual understanding, creativity, and problem solving.

- **Instructional systems need to be carefully structured to optimize teachers' use of time.** Whereas many of the new technologies are intended to introduce efficiencies into teaching, they can also pose significant burdens for teachers. Teachers may have to work harder to integrate technology into their plans, figure out how to use the technology in the classroom, and learn how to manage and interpret any results. Also, while technology can be attractive, when used ineffectively it can potentially waste valuable instructional time. One factor that could contribute to this is adoption of technology for the sake of the technology itself without adequate attention to purposeful integration with curriculum or teacher training. Designers of personalized learning systems must consider how to best support teachers in using their planning and instructional time with maximum efficiency.

- **Educators need to ensure that personalized learning approaches draw on the support that can come from teachers and peers.** As more and more data are collected from digital learning environments, more and more instructional decision making (i.e., adaptations) can be informed by advanced analytical techniques that search for patterns and correlations. Many of these patterns can be opaque to teachers and students, leading to a black box approach that lacks transparency about how instructional decisions are made and may not adequately account for individual learners' contextual factors and responses. Also, much of learning, especially in the early years, depends on teachers' responsiveness to students' academically relevant emotional experiences—their frustration, anxiety, and interest. Technology currently on the market has minimal capabilities for dealing with the array of emotions students experience in the process of learning. Understanding how a system should respond to student disengagement, frustration, and the like is an active research area. Moreover, systems that overemphasize one-on-one computing have the potential to isolate students from their peers and remove them from the powerful impact social learning environments can have on learning outcomes. Where feasible, adaptive systems should recognize and draw on the learning and support that can come from teachers and peers.

Conclusion

Although there are a variety of definitions for personalized learning, the general consensus is that personalized learning refers to instructional opportunities where the objectives, pathways, and/or pace of instruction can be tailored to individual students based on assessments of their needs, interests, and ongoing performance. Technology can play a critical role in how the assessments are delivered to students and how learning experiences are tailored. Tailoring involves student engagement in a learning experience, data collection, data interpretation, and adaptation. These processes facilitate the matching of a learning experience to measurable aspects of individual learners. To be an informed consumer of tools and practices described as supporting personalization is to see how, for example, a technological tool aids in engaging a student in a learning experience, collecting and interpreting data from that experience, and/or adapting a subsequent learning experience. It is also important to be aware of the laws regulating data security and privacy and to recognize that existing research on personalized learning is promising but not definitive about impacts and insufficient for providing strong recommendations for best practices. Finally, in designing personalized learning environments, careful consideration must be given to strategic supports for effective implementation of personalized learning to benefit all students.

3. Personalized Learning in Schools

This chapter discusses the enactment of personalized learning in K–12 schools and explores the following questions: *How are schools creating technology-enabled personalized learning environments? What do they report as the essential elements of their models? What do practitioners and policy makers need to consider when transitioning to personalized learning in schools?* To answer these questions, this chapter draws from an investigation of how 17 school districts and charter management organizations (CMOs) are implementing approaches to personalized learning. These districts and CMOs were nominated by experts as doing important and innovative work. The sample spans geographical locations, grade levels, missions, and funding sources (e.g., Race to the Top – District, Next Generation Learning Challenges). Many other CMOs and districts are implementing personalized learning in important ways, but this sample allowed for a broad characterization of a range of approaches. The ideas presented here are a sampling of how thoughtful practitioners are approaching the design of personalized learning environments. Many of the districts and CMOs are still in the process of getting their approaches up and running. Conducting this inquiry during this formative stage in schools' development and implementation allowed for observations of both aspirations and challenges.

Essential Elements of Technology-Enabled Personalized Learning Environments

This section discusses what educators across the schools and districts reported as essential elements of the personalized learning environments they were creating using technology. The list emerged from the interviews with educators and is informed by insights from recent frameworks for designing personalized learning approaches (e.g., American Institutes of Research, 2013; Childress & Benson, 2014; Friedlaender et al., 2007; Patrick et al., 2013; U.S. Department of Education, 2014b; Wolf & Schneiderman, 2014). No one school or district evidenced all the elements described below, and no element is intended to be enacted in isolation or assumed to be a required condition for personalized learning. This discussion is also not intended to be comprehensive or representative of effective practice. As discussed throughout the report, currently little guidance exists from research about what constitutes effective practice for personalized learning. Thus, these elements were not evaluated in relation to student outcomes or comprehensively in relation to educators' perceptions of success.

Some of these elements were designed differently, depending on student population needs and schools' educational goals. For example, student age was an important factor. In elementary schools, personalized learning may be directed more to developing basic academic and social and emotional skills with strong educator support. In high schools, personalized learning may leverage and support students' greater ability for self-regulated learning and be geared toward preparation for college. Another example was whether or not Response to Intervention (RTI) played a central role in the personalized learning model. In some schools, RTI was used as a gateway for providing tiered instructional interventions for students with learning disabilities and behavioral problems as well as the general student population (Fuchs & Fuchs, 2006).[4]

1. Students are Empowered to Exercise Personal Agency and Responsibility

A core principle for many personalization efforts was increasing the opportunities students had to exercise personal agency and responsibility in their learning opportunities and processes. Educators from several sites described empowering students to choose the learning resources they use to achieve a particular learning goal—allowing students to choose their own *pathways*. For example, some schools allowed students to select a learning modality (e.g., video versus text), topics for projects, or readings aligned with their interests. Some high schools created multiple choice points for students: Students not only selected resources they thought were right for them (i.e., select their *pathways*), but they could also decide when to take assessments (i.e., determine their *pace*). Although educators using personalized learning in formal classroom settings often do not allow students to choose their learning *objectives*, Ito et al. (2013) indicated that such choice can be productive for students. In K–12 schools, choice of pathways, pace, and objectives is often constrained by the fact that schools are accountable for all students reaching common grade-level standards by the end of the academic year.

2. Competency-Based Learning Progressions

Many educators reported that competency-based learning progressions were an important aspect of personalization. The terms *competency based*, *mastery based*, *performance based*, and *proficiency based* can all be used to refer to instruction in which individual students advance through learning progressions at their own pace based on their ability to complete specific assessment tasks. This approach can be contrasted with more traditional ones in which all students in a classroom progress together and the major determinants of advancement are seat-time and overall course grades. Hemelt, Roth, and Eaton (2013) described components of this type of learning as follows:

> (a) break the prespecified objectives into a series of smaller learning units; (b) teach each unit for mastery—using formative assessments to uncover gaps in student understanding; (c) use a flexible "correctives" process tailored to the specific weakness of students, as identified in the formative assessments; and (d) evaluate each student's mastery of material over the course as a whole on the

[4] Educators must remain cognizant of their federal civil rights obligations to ensure equal access for all student populations, including students with disabilities. See the end of Chapter 1 for more information.

> basis of achievement relative to the standard of mastery set up at the beginning, and not relative to the performance of other students. (p. 417)

While competency-based learning is sometimes treated as synonymous with personalization (Means et al., 2014), it is only part of the personalization; competency-based learning may not address the use of different pathways of learning, nor does it automatically address tailoring instruction to students' interests. Competency-based learning progressions were found to organize individual lessons, units, and entire courses, depending on the needs and structure of the informant organization.

3. Blended Learning Opportunities

Blended learning—in which instructional time inside and outside school is apportioned between direct instruction from teachers, individual written work, group work with peers, and time spent learning with technology—was an essential element of most of the approaches to technology-enabled personalized learning. In blended learning, educators use both face-to-face and online instruction in which students have some element of control over the pace, time, place, and/or pathway of learning (U.S. Department of Education, 2010a). Although blended learning can take place in a variety of configurations, most of the schools used one of the two variations of what is called a *rotation model* (see Staker & Horn, 2012). In a *station rotation model*, the classroom is set up with a number of stations, some with technology and some without, and students rotate through them doing combinations of online work, group work, whole-class instruction, and individual offline work. A *lab rotation model* is similar, but instead of rotating within a classroom, students rotate through activities in different locations on the school campus. Blended learning models can support personalized learning by providing multiple simultaneous instructional opportunities, so students can use different learning approaches and resources, some of which can be tailored specifically to their individual needs. For example, the software used by students can be adaptive, allowing them to work at their own pace and ability levels. Moreover, blended learning models can potentially introduce new efficiencies for teachers by helping them manage complicated differentiation of instruction and freeing them to give students individualized attention. One of the primary reasons for grouping students is that it enables teachers to tailor learning opportunities for the groups. Teachers can thus attend to the individual needs of students grouped homogeneously or heterogeneously while other students are receiving instruction online that is tailored to their individual needs. Some educators described these strategies as helping them more closely mimic one-on-one tutoring in which students get optimal individualized attention.

4. Individual Learning Pathways

In some schools, educators used or were planning to use *personalized* or *individualized learning plans*. Personalized learning plans (PLPs) can contain short- and long-term academic goals that a student will focus on along with strategies for how the student's learning will be structured with respect to objectives, pathways, and/or pace. Building on the emphasis of student ownership, schools expressed an interest in having PLPs developed through collaboration between the

student and the teacher and, in some cases, parents and other educators. PLPs may include noncognitive elements, such as social and emotional learning goals or 21st century skills. They may include interim goals directly linked to formative assessments that students and teachers can use to ascertain ongoing progress toward long-term goals. In some schools, teachers meet individually with students at regular intervals (e.g., 6 or 10 weeks) to discuss progress on their PLPs and plans for the future.

5. Frequent, Immediate Feedback

Assessment and feedback are critical to tailoring and may include ongoing formative assessments, quizzes, and checks for understanding. These types of measures may or may not be embedded in technology and are typically complemented by traditional types of diagnostic and summative assessments. One assessment approach used in several settings was the Northwest Education Association's Measures of Academic Progress (NWEA MAP), a set of online adaptive assessments designed to identify a student's proficiency level in mathematics and English language arts. While the NWEA MAP was administered to students one to three times a year, teachers described modifying instruction in line with much more frequent progress monitoring and formative assessments, such as those that came with their curriculum packages and those they developed themselves. Educators also described using short quizzes and check-ins that they themselves developed in order to gauge where students were and what if any modifications needed to be made.

6. Culture of Self-Regulated Learning

In many cases, educators who emphasize opportunities for students to exercise personal agency and responsibility in their own learning processes are also concerned more generally with creating a culture in which students are supported in developing the academic mind-sets, learning strategies, and self-regulated learning behaviors that are necessary for empowerment. The mind-sets encouraged may include a mastery orientation, such that students are fundamentally motivated to work to master content rather than simply get good grades (e.g., Maehr & Zusho, 2009), or a growth mind-set, such that students understand that their intelligence grows with their effort, good strategies, and help from others (e.g., Yeager & Dweck, 2012). Connecting learning to students' personal interests and long-term goals can also promote student ownership. Learning strategies may emphasize student responsibility for planning learning goals, monitoring their current progress, strategizing about next steps for reaching their goals, and reflecting on their learning processes (e.g., Winne, 2011; Zimmerman & Compillo, 2003). Even though research on how to promote these noncognitive factors is still in early stages, promising studies have shown that these types of mind-sets and strategies can be explicitly taught and instilled by educators, for example, in the ways they frame assessment activities or explain why learning can be challenging (e.g., Yeager & Walton, 2011) or through explicit modeling and instruction (Dignath, Buettner, & Langfeldt, 2008). Some educators emphasized the importance of providing opportunities for students to take a central role in planning their learning, using data to understand their own learning preferences, and finding ways to connect personal interests and long-term goals.

7. Strong Teacher-Student Relationships

In their research on school reform, Darling-Hammond, Friedlaender, and colleagues reported on five case studies of schools identified as providing excellent outcomes for low-income students of color (see Darling-Hammond & Friedlaender, 2008; Friedlaender et al., 2007). This research identified "personalization" as a key and distinguishing feature of all five schools. The researchers defined this term with respect to ensuring that students know others well and feel well known by teachers and their fellow students. This has two important benefits: Teachers understand students' individual needs and can adapt instruction to those needs, and students have strong relationships with peers and adults that promote a sense of belonging and provide critical resources for dealing with challenges such as the stresses of poverty, racism, and inadequate access to health care, housing, and employment.

For many of these reasons, strong teacher-student relationships was a common theme in the interviews. This was typically emphasized in elementary school grades and was less common in upper grades, but some middle and high schools were emphasizing this type of personalization through small class sizes, block scheduling, self-contained classrooms throughout the day, teacher looping (i.e., students staying with the same teacher for a given subject for successive years), and/or an advisory system in which teachers took on long-term responsibility for a small group of students.

8. Engaged Parents and Guardians

Many schools identified the increasing role of parents and guardians in supporting personalized learning opportunities. For students with documented special needs, parents' roles have been guaranteed under the Individuals with Disabilities Act as members of an Individualized Education Plan team for over 40 years. Beyond this legal requirement, parents are seen more and more as a resource in tailoring learning opportunities for students. Many parents can provide educators information on the best learning environments for their sons and daughters and can support personalized learning after school hours. Some schools invited students and parents to work together with the teacher to develop PLPs. Technology often played a critical role; some schools regularly shared data and progress reports with parents online to facilitate communication and spark conversations.

9. Restructured Roles for Educators

Some approaches to technology-enabled personalized learning required significant shifts in educators' roles and capacity. One common shift for teachers was from being primarily directive and didactic to making extensive use of coaching or one-on-one and small-group instruction. As part of this shift, some schools created new staff positions. For example, new instructional personnel were hired in many cases to manage students working in small groups and during one-on-one tutoring or independent work time or to oversee students working in digital learning environments. Some schools had established a professional development pipeline whereby newly hired teachers started out as group facilitators and eventually advanced to become classroom teachers.

Another common shift for teachers was a greater focus on curation and management of instructional resources. To call teachers curators and managers is not new; however, what and how teachers were curating and managing appeared to be changing in some schools. Some teachers reported that they spent a lot of time creating and organizing students' access to digital resources, for example, by generating individualized playlists that differentiated instruction for students with different needs and abilities.

10. Enhanced Educator Capacity

Along with shifting roles, many schools incorporated building teacher capacity into their overall approach to personalized learning. Principals may also be supported as they enact new visions for their schools. In most cases, personalization efforts required teachers to use new tools and practices to understand individual students' learning needs, adapt or differentiate instruction, curate materials, manage class time and multiple concurrent activities, and support students' choice, agency, and responsibility for their own learning. School systems varied in what areas of teacher knowledge and practice they chose to concentrate on in teacher professional development. Some focused on helping teachers learn how to effectively integrate digital resources into instruction. Others emphasized using data and data-driven decision making in their instruction. Some worked on strategies for differentiating instruction, some on RTI methods and interventions. Whereas most schools concentrated on a particular area of professional knowledge, some provided training across multiple areas. In some schools, the emphasis was on using external supports such as professional networks, technical assistance offered by a funder, or external consulting and partnerships. In the interviews, CMO representatives often highlighted the various external resources that they used and shared both inside and outside their charter network.

11. Infrastructure and Support

Many schools modified or enhanced the technical infrastructure, facilities, and/or school schedule to support personalized learning. Technical infrastructure included additional mobile devices and wireless broadband Internet access. Many schools worked to find ways to provide low-income students and parents with connectivity outside school, for example, through partnerships with local companies to provide discounts on broadband and devices and partnerships with local community centers to provide technology hubs. Some CMOs and districts developed an infrastructure for storing and integrating data across various systems and made data accessible in a useful way for students, teachers, and parents. Some schools also constructed their own open-content systems for managing and delivering personalized digital content, assessments, and feedback.

The physical arrangement of classrooms and modifications in school scheduling were also parts of some approaches to personalized learning. Some schools created open spaces for blended learning in which students had the freedom to move among rotation stations, get coaching from teachers and other adults in the classroom, and work collaboratively with peers. In some schools, personalized learning was supported through extended school days, block scheduling, or year-

round schooling. Such modifications created opportunities for students to receive extra instructional time, enabling students who needed remediation to catch up to grade-level standards and expectations.

As discussed elsewhere in the report, ethical and legal considerations in developing such infrastructure are the accessibility of technology for students with special needs and disabilities (Chapter 1) and ensuring that all systems appropriately support the protection of student data and privacy (Chapter 2).

12. Strong Educational Leadership Focused on Technology-Enabled Personalized Learning

Many site-based leaders, such as school principals, assumed new responsibilities for implementing and sustaining personalized learning approaches (see U.S. Department of Education, 2014b). As organizational leaders, these individuals needed the capacity to enact complex visions of educational models that in many cases diverged significantly from traditional ones. Such leaders are responsible for bringing into reality each of the key elements of their model of technology-enabled personalized learning, which often requires new kinds of decisions about school culture, instructional leadership, staffing, capacity building, and development of physical and technological infrastructure. Multiple schools also created new or modified organizational structures, including new administrative positions with staff in charge of blended learning, RTI, technology coordination, and data coordination more generally.

A Personalized Learning Vignette: Summit Public Schools

The elements described above were enacted in multiple combinations across schools and organizations. Below, the ways that one CMO—Summit Public Schools—organized principles and strategies into a coherent personalized learning approach are described.

Summit operates nine high schools and serves about 2,000 students in the San Francisco Bay Area and Washington State. Its mission is to prepare a diverse student body for success in college and to be thoughtful, contributing members of society. Summit aims to prepare students to be independent lifelong learners through schools that are personalized, empowering, and rigorous. Learning at Summit is organized around multiple core learning experiences. For example, learning is blended across online and face-to-face opportunities as well as organized around rich project-based learning experiences, all of which help foster deeper understanding of content and further cognitive and noncognitive skills referred to as “habits of success.”

Students spend a majority of their class time in project-based learning with their teachers. During this time, the focus is on solving real-world problems and cognitive skill growth. Summit teachers use a comprehensive cognitive skills rubric to assess student growth in 36 discrete Common Core-aligned cognitive skills across all subject areas from grades 6 to 12. Teachers can track student growth in every skill over time and encourage improvement among students from all skill levels.

Along with project-based learning experiences, students are provided dedicated time to read and practice math problems referred to as "Summit Reads" and "Summit Solves," respectively. Students are also provided time to work with their assigned teacher mentors, which is intended to further their academic habits of success in setting goals and managing their own learning.

Core learning experiences at Summit are supported by a homegrown technology platform called the Personalized Learning Plan (PLP). The PLP gives students access to a dashboard that enables them (and their teachers) to monitor their progress toward competency in each content area, set goals, and access online resources. Students have allotted time during the day referred to as "personalized learning time" during which they work at their own pace on online playlists and take assessments to demonstrate mastery of objectives that are aligned to the playlists. Students experience learning opportunities tailored to their individual needs with respect to objectives, pathways, and pace. For example, personalized learning time is competency-based in that students can work through assessments at their own pace using resources that they select.

Summit teachers expect students to take responsibility for their own learning, and students are expected to identify for themselves when and how they might best progress through content. Student choice and personalization work together when, for example, students who did not pass an assessment decide what they should do next. If students feel like they truly know the material, they can take the assessment again; otherwise, they can continue learning with another resource on the playlist.

The personalized learning approach Summit uses shifts educators' roles significantly from those typical in classrooms. Teachers are less directive and didactic and are more involved in coaching, managing, and supporting learning during project time—one on one, in small groups, and through Socratic seminars. They also are actively involved in curating the learning activities in the PLP system. Most important, every teacher mentors approximately 20 Summit students, helping them develop as self-directed learners who are prepared for college and career.

Operational Challenges When Transitioning to Personalized Learning

Educators reflected in the interviews on the key challenges they have faced in the early phases of implementing personalized learning environments. In navigating the complex path from theory and plans to effective practice, many were working out a myriad of issues: instructional, practical, technical, and systemic. The following were the foremost challenges:

- **Managing multiple changes.** The shift to personalized learning often causes multiple simultaneous changes—changes to schedules, technologies, curricula, planning time, and interactions among colleagues. Given the all the moving pieces that can be associated with systemic change, teachers can have difficulty prioritizing their efforts. They are often required to combine skills: differentiating instruction for individuals or groups, organizing a blended learning classroom to allow multiple activities to occur at once, using data to make informed instructional decisions, and integrating technology into practice, to name a few. In addition, while teachers often appreciated the ability to spend more time with students who most needed their help, they had to simultaneously ensure that other students were productively engaged. Further, teachers also noted that it can be challenging to plan for and

manage classrooms in which students are working on different content and following different learning pathways.

- **Setting appropriate learning goals.** In schools that were using personalized learning plans, teachers needed clear guidelines for making decisions about student goals. The challenges were particularly apparent for students who lagged behind their peers in academic abilities and who had to make more than a year's worth of progress to begin to meet grade-level standards. Teachers described the need for help in setting growth targets that were accelerated but realistic.

- **Selecting appropriate instructional resources.** In a world of quickly changing technologies and instructional materials, educators described the challenges of finding the right set of resources to support each child's learning along with the right instructional models to support meaningful integration of technology. Teachers reported the problems of the incompleteness of available content relative to all areas of the curriculum standards they were responsible for and the inconsistent quality of some of the materials from vendors.

- **Integrating data and managing log-ins from multiple sources.** Most schools used an assortment of software and systems to meet all their instructional needs in the classroom. For schools and teachers, this often meant that a variety of different types of data were available from different systems and were not integrated into centralized dashboards and displays they could use for decision making. It can also be difficult for teachers and students to manage multiple passwords and accounts. Many schools are working to find solutions that make it easy for students to log in and that align data across multiple systems to support measuring, interpreting, and acting on data.

- **Ensuring the technological infrastructure is adequate.** Setting up blended learning environments requires infrastructure, such as a sufficient number of devices, adequate bandwidth for connectivity, on-site tech support staff, and places to charge mobile devices. Technical difficulties or insufficient infrastructure were among the most cited barriers to implementing PLPs.

- **Partnering productively with parents.** Personalized learning is a shift not only for many teachers, but also for many families. Parents often need orientation and understanding of what personalized learning is and how it can support student learning.

- **Costs.** Moving to personalized learning approaches can be expensive for schools. Requirements for hardware and software, teacher staffing and training, and facilities improvements can be difficult to fit within existing school budgets.

Conclusion

As many educators were quick to note, changes are occurring quickly, and the schools' personalization efforts will look completely different in a short time. Many schools implementing personalized learning appeared to be adopting a rapid prototyping and iteration approach by trying new approaches, seeing how they work, and making necessary modifications.

Many educators implied that schools offer rich opportunities for student learning that may or may not be specifically designed for personalization. Thus, the issue many schools are facing is not how to personalize instruction per se but how to create the best learning opportunities for all students. Personalization represents a powerful set of strategies for creating individually optimized learning opportunities.

Finding ways to collect more targeted and timely data, interpret the data relative to what is best for students, and match learning experiences to individual students represent a collection of practices that could lead to higher probabilities of students attaining competency. Although there remain questions about the quality and timeliness of data, the efficacy and validity of decisions made using those data, the accuracy of matching, and the true uniqueness of learning opportunities, practitioners, researchers, and policy makers are all approaching these questions to the long-term betterment of students.

4. Using Technology to Enable Personalized Learning

Building on the discussion of educational approaches in Chapter 3, this chapter explores the kinds of technologies that support this work in schools, with the goal of informing educators, school leaders, and families as they navigate the quickly evolving world of technology. Specific questions addressed are: *In what ways can technology foster personalized learning? What are some examples of these technologies, and how do they work? What are the current limitations of technology and potential for the future?* Answers to these questions come from interviews with leaders from technology vendors that provide widely used educational technologies for supporting personalized learning in schools, complemented by the lessons learned from the literature and interviews with researchers and educators. This chapter is not intended as a review or cataloguing of personalized learning technology or technology vendors; rather, it presents the roles that technologies can play in supporting personalized learning.

As discussed elsewhere in the report, ethical and legal considerations in understanding these technologies are accessibility for students with special needs and disabilities (Chapter 1) and ensuring that all systems appropriately support the protection of student data and privacy (Chapter 2).

Roles for Technology in Supporting Instruction

Personalizing learning involves adjusting the objective, pathway, and pace of instruction based on learner interests and ongoing performance. As discussed in Chapter 3, three common elements of personalized learning environments are that they empower students to exercise personal agency and responsibility, are organized around competency-based learning progressions, and are enabled by blended learning opportunities. Technology plays a critical role in such learning environments. Three roles for technology are highlighted:

- **Automated adaptation of learning opportunities.** Theories of learning suggest that students learn best when they are optimally challenged, when material is difficult enough to engage them in deep cognitive work but not so difficult that they cannot learn or they become frustrated. Adaptive learning systems monitor student progress and make appropriate adjustments to instruction to support and enhance learning. Such systems can support a

competency-based instructional model by providing students the opportunity to master content at their own pace or through a chosen pathway. They are often used in the implementation of blended learning models in which students rotate through online and offline stations.

- **Resource curation and management.** There are many online curriculum activities, apps, instructional videos, educational games, interactive websites, and the like, and teachers and students need support in finding the ones that match individual student needs. A class of technology systems provides support for finding and selecting resources that fit learning needs, for managing students' access to and use of resources, and for assessing how well students learned with the resources. Using these kinds of systems can support student choice and agency and competency-based learning. Along with adaptive technologies, they can be used in the implementation of blended learning models.

- **Use of student data.** A critical challenge for educators is making sense of data from a variety of sources—assessments and other data from online systems, state assessments, district benchmark exams, student school records, measures of students' preferences and interests, and indicators of behavioral issues—and using the data productively for personalizing learning. Many technological supports, on their own or as part of particular systems, provide data integration mechanisms and data displays that enable personalization. Data displays can also be integral to adaptive learning systems and resource curation platforms. Providing intelligible and actionable data can be a critical support for student agency, competency-based learning, and the management of blended learning models.

As discussed in *Learning Technology Effectiveness* (U.S. Department of Education, 2014e), it is important to note that technology by itself is not a silver bullet. These roles enable and support personalized learning as part of a complete educational system that combines many factors, such as those discussed in Chapter 3. Technology is a means to an end, not the end in and of itself. There is also considerable variation in the quality of various technologies and in how they are used.

The sections that follow explore each of these roles of technology more closely. The subject of these sections is technologies that directly support tailoring instruction. Other types of technologies that can support personalized learning are beyond the scope of this chapter. These include the myriad of online resources themselves (e.g., curriculum activities, apps, instructional videos), technologies such as social media that can support the interpersonal relational aspects of personalization, and the technological infrastructure needed for supporting personalization at the school or district level (e.g., see Glowa, 2013). Also not considered in this chapter are the intricacies of the algorithms that power adaptive technology, such as recommendation engines, student cognitive models, and decision rules.

Technologies That Automatically Adapt Learning Opportunities

Adaptive educational systems are perhaps the most popular and widely recognized types of technology supporting personalized learning. A report from the National Academy of Education defines the core feature of such technology:

> Whatever the individual learner characteristics or the dimensions of the learning experience represented in the system, the key defining feature of adaptive educational technologies is that one or more elements of the system are modified in response to information about the learner. It is this adaptivity that creates the personalized learning experience intended to maximize the learning of each student. (Natriello, 2013, p. 1)

This adaptation can be continuous, and according to researchers Shute and Zapata-Rivera (2012), "Adaptive educational systems monitor important learner characteristics and make appropriate adjustments to the instructional milieu to support and enhance learning" (p. 7).

In schools, common adaptive educational systems are stand-alone software programs that teach the content of a single subject. Adaptive educational systems take students through tailoring cycles such that, as introduced in Chapter 2, the system provides a learning experience in which a student *engages*, data are *collected* about what the student knows or how he or she is learning, the data are *interpreted* with respect to information about learning pathways, and the system then *adapts* the learning experience based on the student's current needs. In essence, the technologies adjust instructional or pedagogical actions that are designed to influence learning, using interpretations of what and how students are learning (Koedinger, Booth, & Klahr, 2013). On the basis of an assessment of learning, an adaptive technology can adjust in a variety of ways: It can offer differentiated instructional tasks, hints, prompts, related resources to study; extra homework; and/or, when relevant, more challenging material. Technology can vary the ratio of examples to problems, the concreteness of examples, the timing of feedback, the grouping or sequence of topics, and whether the student or the system explains how problems are solved.

These adaptive functionalities are typically designed in accordance with a driving theory of learning. Depending on the system, the theory may be based on observations of how knowledge in a given content area is organized and interrelated, how typical learners engage with content, how expert tutors support the learning of typical students, and how expert teachers make instructional decisions. Adaptations occur at a fine-grained level informed by this theory. For some technologies, data from students' interactions with the system are used to refine the theory through experimentation. Many systems break down complex concepts into smaller chunks or subskills for instruction and practice (e.g., the carrying operation as part of understanding how to add two-digit numbers) and conduct ongoing embedded checks for understanding that inform how the system will adapt. In systems used at large scale, data mining techniques are being used to support the optimization of content sequencing.

Two specific kinds of adaptive systems that are popular in many schools are cognitive tutors and competency-based systems. **Cognitive tutors** are systems that diagnose specifically what students understand, what they do not, and why in order to provide the kinds of hints, prompts, and scaffolds that a human tutor would. Like human tutors, cognitive tutors are tuned to the kinds of knowledge or skill being learned, the type of student doing the learning (e.g., based on prior achievement), and the context for learning. One example of such a system is Carnegie Learning's MATHia® (https://carnegielearning.com/). MATHia provides virtual math tutors that determine students' problem-solving operations and deliver hints to aid them in the specific ways they need support. As needed, these tutors also offer worked examples or examples of other students' work as additional scaffolds. Another example is DreamBox Learning® (http://www.dreambox.com), which provides supplementary math games for elementary grades.

As students play the games, the system automatically records what they are doing, looking to detect common errors and misconceptions. Then, depending on the types of mistakes detected, the program adjusts the difficulty, scaffolding, sequencing, number of hints, and/or pacing. At the college level, the Expert Electronic Coach (E^2Coach; http://sitemaker.umich.edu/ecoach/) at the University of Michigan provides tailored messages to physics students as they move through the course. E^2Coach collects information from students using self-report measures and measures of academic progress and, based on the patterns observed in data on thousands of past students, provides students study strategies that are unique to them and their progress in the course..

Adaptive **competency-based systems**, most prominently for math and reading, tailor the pace at which students progress through learning activities by tracking what each student has mastered and tailoring an appropriate sequence for subsequent learning objectives. These objectives can include the specific skills to learn next and the level of sophistication at which these skills are developed. In mathematics, some examples are Khan Academy (https://www.khanacademy.org) and Reasoning Mind (http://www.reasoningmind.org), which each take students through a series of learning objectives for a particular subject area or grade level. Khan Academy does not prescribe how teachers use its product, so many different use models exist (Murphy, Gallagher, Krumm, Mislevy, & Hafter, 2014). Typically, it serves as supplemental curriculum for any grade, and teachers choose whether to assign certain topics to different students, assign the same topic to all students, or have students progress through the sequence that Khan Academy has laid out. Students must answer a certain number of questions correctly to prove mastery of a skill and move forward, and they can use videos or hints for support. Reasoning Mind is used as a core or supplementary mathematics curriculum. It delivers direct instruction as a teacher might while students record notes in a paper notebook before being assessed on their understanding of material and the quality of those notes. It then offers simple practice problems, and if students show mastery in solving them, adapts to provide problems requiring deeper understanding and more sophisticated approaches. Teachers play an important role in the system, receiving ongoing feedback about student progress that they can use to provide further adaptive instructional interventions.

In reading, examples of competency-based systems are Achieve 3000® (http://www.achieve3000.com) and READ 180® (http://read180.scholastic.com), which use diagnostic assessments to differentiate instructional materials. In Achieve 3000, students within a given class read text passages about the same content; the difficulty of the text is differentiated to match each student's individual Lexile reading level. Presenting the same content at different reading levels enables a whole class to work together on shared reflection prompts and to discuss the same age-appropriate content while presenting accessible readings for each student. In READ 180, students are assessed for their Lexile reading levels four times per year. The system uses these data to guide them to read increasingly complex texts. Lessons often begin with short videos to build students' background knowledge and then provide passages for students to read before they answer comprehension questions to close each lesson.

Designers of adaptive learning systems are beginning to explore how to incorporate supports for self-regulated learning. Research in psychology (e.g., Dweck, Walton, & Cohen, 2011; Yeager & Dweck, 2011; Yeager, Walton, & Cohen, 2013) has shown that in many situations, students are more likely to persist and succeed at challenging academic tasks when they have (1) a growth mind-set—the belief that their ability and competence grow with their effort, strategies, and help

from others—and (2) a toolkit of learning strategies to help them reflect on their own understanding and try new approaches. Some technology developers are beginning to explore how to incorporate supports for developing these mind-sets and strategies. For example, as students work on mathematics problems in Khan Academy, the system sometimes provides them with reminders such as, "Your brain is like a muscle. The more you flex it, the more powerful it gets!" The system also provides students with a "Why? Why? How?" strategy that encourages metacognitive reflection on their approach to doing problems. As another example, the Math 180 curriculum focuses explicitly on establishing a supportive classroom culture and teaching students about productive mind-sets and learning strategies. This occurs through teacher-led lessons about the brain. Designers are only just beginning to try out these strategies and research is not yet available to demonstrate impacts on persistence or learning.

Technologies That Support Resource Curation and Management

Another important way that schools are tailoring learning experiences to individual needs and interests is by individualizing the online learning resources students use. Teachers and students can draw from a vast array of available resources, such as adaptive learning systems and other types of online curriculum activities, apps, instructional videos, educational games, interactive websites, and so on. As revealed in the interviews with educators (reported in Chapter 3), navigating through the variety of quality resources to find just the right match for a given student at a given time can be challenging. This section discusses a class of technology systems that support teachers and students in curating and managing resources.

Technologies that support curating and managing instructional resources are typically open-content systems, platforms that integrate free and fee-based educational resources (e.g., apps, websites, collections of resources) into one unified log-in and delivery interface (see Education Growth Advisors, 2013). In most cases, these are delivered to students in the form of their own personal playlist of educational activities and assessments. Open-content systems typically have underlying mechanisms to guide how content is selected, managed, and used and mechanisms that support assessment of learning. In contrast, closed-content systems operate as stand-alone systems that cannot be augmented or expanded. They are typically crafted to support a particular sequencing of instruction, practice, and assessment and can be incorporated into open-content systems. For example, the adaptive technologies discussed above are closed-content systems.

Two popular open-content systems that technology designers are building and operating to support personalized learning are content curation systems and learning resource platforms. **Content curation systems** have underlying vetting and search processes for enabling teachers or students to find resources for a particular instructional need. For example, Gooru (http://www.goorulearning.org) provides a search engine with artificial intelligence that uses information about the student and his or her learning to recommend resources and target searches. Students or teachers can control what goes in their playlists. Another example, eSpark (http://www.esparklearning.com), supports curation with respect to diagnostic assessments and personal learning plans constructed by the teacher and student, recommending mobile apps that match student learning goals. It has embedded assessments that can be used to determine whether and when students have mastered the learning goals in their plans.

Learning resource platforms such as Education Elements (http://edelements.com), Agilix Buzz™ (http://buzz.agilix.com), and Difference Engine (http://www.difference-engine.com/) provide centralized access to a customized set of content providers. These open-content systems collate learning data from the content providers and display the data for teachers and sometimes recommend how to adapt instruction. Education Elements partners with schools to help them build personalized learning systems with varying instructional content. Its customized platform provides teachers with a dashboard that enables them to monitor student progress across content systems, informing decisions about grouping, remediation, or acceleration. Agilix Buzz, custom built for personalized learning in the Michigan Educational Achievement Authority, integrates a number of disparate learning tools and content from multiple vendors into one platform so that students can follow multiple learning pathways through a curriculum aligned with local standards. Students choose objectives to work on and also select the assessment activities they want to complete to demonstrate their mastery of the objectives. At the college level, Difference Engine provides infrastructure for integrating multiple learning resources and data sources to support adapting online learning experiences.

Learning resource platforms are different from **learning management systems** (LMSs), such as Schoology (https://www.schoology.com/) and Canvas (http://www.instructure.com). An LMS facilitates synchronous and asynchronous communications among students and the teacher, as well as file sharing and resource storage and management. These systems are not typically used for personalized learning specifically, and they do not aggregate and display data from the learning resources they are used to manage.

Along with the above systems are **web-based repositories and communities** to help teachers find the resources they need. For example, the U.S. Department of Education is creating a registry of learning resources on the website http://free.ed.gov. The nonprofit organization Common Sense Media has a website called Graphite (http://graphite.org) where teachers can rate digital tools and resources, and the popular website EdSurge has an Edtech Index (https://www.edsurge.com/products) that is populated by the community of developers of apps and tools. Websites for sharing lesson plans—http://betterlesson.org and http://teacherspayteachers.com—enable teachers to search databases based on lesson topic.

Technological Supports for Using Student Data

This section discusses technological supports that, on their own or as part of the kinds of systems described above, provide intelligible and actionable data for tailoring. Tailoring learning requires regularly monitoring students' learning progress and needs, formally or informally, and matching learning activities in response to those needs. Data can come from a variety of sources—for example, assessments and other data from inside adaptive learning systems or open-content systems, state assessments, district benchmark exams, student school records, measures of students' preferences and interests, and attendance data. Vendors should work with schools to provide assurances that the data will be kept securely and that privacy will be strictly protected, as required by FERPA, COPPA, and any other relevant state or federal policies (see Chapter 2). A critical challenge for educators personalizing learning is determining how to integrate and use productively the data from this variety of sources. Prerequisites and supports for data-informed

decision making have been identified (U.S. Department of Education, 2009a) and include tools for generating actionable data, professional development and technical support for data interpretation, and tools for acting on data.

The following data are collected at various key time points in the learning process:

- **Baseline or diagnostic data.** Many systems use baseline diagnostic assessments or surveys to obtain an initial indication of students' learning needs and preferences. Some systems import scores from the previous year's standardized tests, and others administer their own baseline assessments to determine how to place students. For example, Khan Academy has created an extensive diagnostic process that aligns with its knowledge map; Achieve 3000 and READ 180 give assessments to determine students' Lexile reading levels.

- **Formative assessments and check-in surveys.** Some systems efficiently administer formative assessments on learning and surveys that let the teacher take the pulse of the classroom. Computer-based assessments can be adaptive (i.e., changing the questions asked in response to answers from earlier questions), they can be given to students right at the moment they should have learned a concept, or they can be timed to be delivered later to ensure that content is being retained. Some systems, especially for early grades, provide students the opportunity to communicate their mood and request a talk with a teacher. Surveys of mood can help with personalization by enabling students to express their needs so they can be addressed.

- **Online learning process data and unobtrusive assessments of progress.** As students interact with adaptive or open-content systems, the systems can collect a number of types of data about how the students are engaging in the learning process and their learning progress. For example, systems can collect data about correctness of responses, strategy use, guessing, help-seeking, gaming the system, persistence, and so on. What data are collected and when they are collected shape the inferences that can be made about learning. For example, getting a problem correct immediately after learning a concept does not necessarily suggest the student has attained long-term mastery. How quickly an answer is given may be important for measures of fluency in reading, mathematical skills, or language learning.

- **Assessments of mastery.** In competency-based learning, assessing mastery of particular learning goals is important. This can determine when students are ready to move on to the next activity or learning goal.

Data management systems consolidate and display data from different online learning platforms and student information systems to support goal setting, adaptation, and the assignment of learning materials for specific students. Vendors work with schools and districts to identify data, store the data securely, and ensure that the system complies with state and federal statutes to protect student privacy. For example, Illuminate Education, Inc.™ (https://www.illuminateed.com) is an "all-the-data" platform intended to integrate a multitude of administrative websites into a dashboard and to automate such tasks as taking attendance, entering grades, and analyzing test data. Illuminate provides a tool called Activate that uses the data to make personalized recommendations for learning resources. Students can also view a dashboard of their own data. eScholar® (http://www.escholar.com), a data warehouse and

analytics company, provides accountability infrastructure. Its MyTrack® service consolidates data and provides a platform for using data to set goals, assign related content, and track progress toward the goals. At the college level, the Education and Career Positioning System (http://www.epsdevice.com/), used at Lone Star College-University Park, provides students a tool for developing personalized college-to-career pathways. This platform enables students to access, combine, and aggregate a wide array of lifelong personal information and educational records, develop a personal profile, and use these data to explore career trajectories, make decisions about programs of study, and connect with potential employers.

Across all types of adaptive learning systems, the design of dashboards for displaying data is critical to how teachers, students, parents, and administrators can use the data. As they engage in instructional decision making inside and outside the classroom, teachers at a given moment are likely to need to see what is happening overall in the classroom, how individual students are doing, and how different students may be doing with respect to particular standards or skills. Some dashboards also may provide teachers with self-report information and feedback from students. Reports from students themselves, particularly in the earlier grades, on how they are feeling emotionally or whether they like certain learning materials, are increasingly being included in data management systems to help inform teachers' instructional decision making. Students also need information about the progress they are making. Dashboards for students must provide timely data that support their sense-making and promote self-regulated learning. The way the data are displayed and presented to students can significantly affect their motivation, for example, whether it emphasizes successes rather than struggles. Because dashboards are typically visual in form, consideration must be given to accessibility for students who are visually impaired. Many platforms also include dashboards for administrators and parents, each displaying different types and amounts of information to expand transparency, dialogue, and ownership. Such dashboards are designed to show progress at the school level and/or individual level to help these stakeholders support personalized learning in the classroom.

Limitations of Technology for Enabling Personalized Learning

Many educational technologies purport to personalize learning, so it is important for teachers, parents, and administrators to understand the capabilities and limitations of technologies. Two general limitations are that little research is available on the effectiveness of most technology products (U.S. Department of Education, 2014e) and that technologies are worthwhile only if educators, students, and parents know how to use them properly. Other limitations can be difficult to determine from the materials provided by vendors or from white papers and testimonials from other schools. Often, these materials are short and, unless they link to a report from an external evaluator or researcher, are based on internal analysis that can lack objective rigor or valid measures of effectiveness. This section summarizes some important limitations of technology.

- **Interpretation and use of data are limited by the quality and types of data available.** Data from technology systems are susceptible to all the limitations of assessment data in general. For example, because most of the technologies discussed rely on simple inputs, such as short constructed responses and multiple-choice responses, it may be difficult to capture

data and make inferences about students' conceptual understandings and other more conceptually complex processes, such as applying, analyzing, and evaluating. Dealing with more open-ended responses, such as writing tasks, is an emerging frontier. Interpretation of data may also be limited by a lack of contextual information. For example, without additional information, it might be difficult to identify what led to a particular low score. This is important because different causes might require substantially different types of intervention.

- **Content recommendation systems may have sophisticated search engines, but automating the match of materials to learner characteristics and needs is yet to be achieved.** Whereas sophisticated search engines enable searches based on features of learning resources such as quality, resource format, publisher, and topic, the question of how to automate the match of learning resources to learner characteristics and needs remains unsolved. In fact, it is still unknown whether content recommendations are improved when they take learner characteristics beyond proficiency or prior achievement into consideration. Because of these limitations, curation systems still require active teacher participation—typically in creating playlists—to help students access the materials best suited to their needs.

- **Best practices for the integration of data from multiple sources are still under development.** Many vendors talk about building student profiles, but such profiles do not generally integrate data from multiple sources, such as other online learning environments. Each individual technology is designed to collect its own data about a student and to display the data via a dashboard. Such data are rarely exportable to common formats. Furthermore, off-technology activities, such as project-based work, are typically not captured by technology at all. One immediate drawback of the lack of integration is that when a student completes working with one technology, he or she needs to establish a baseline again with the next technology. Further, gaining a comprehensive understanding of a student's progress can be difficult when the student works with many different learning systems. Although standards for exporting student data are being developed (MyData, https://www.data.gov/consumer/mydata-office-of-educational-technology/), their use is uncommon.

- **Technology companies are still working on ways to make multiple sources of data truly understandable and actionable by teachers.** During the past decade, the push to personalize learning has led many companies to transition from a passive role of archiving learning data to a more active role of helping teachers and administrators interpret the data to support conclusions about next steps. Illuminate and eScholar are both examples of technology vendors that were conceived to store student data but now more actively support personalization (through Illuminate's Activate portal and eScholar's MyTrack portal).

- **Not all systems are adequately engaging for all students to ensure that blended learning approaches will work consistently.** In learning environments where students work independently on computers, concerns can arise about their engagement. Technology companies and researchers are studying ways to determine whether students are being productive on computers (e.g., sensing boredom, frustration, and so on) and seeking effective ways to remedy disengagement. This is still a research area, however, and technologies that are claimed to automatically detect emotions and behaviors are not yet reliable enough for public use. Understanding how a system should respond to disengagement and frustration

and the like is also an area of active investigation and experimentation. Should systems strive to eliminate frustration? Does frustration have value? Is it possible for systems to learn the frustration point of individual students to intervene only when necessary? Developers are some distance away from having answers to these important questions.

- **In adaptive systems, much work remains to be done to develop robust principles for how adaptations should be made.** Although researchers and technology developers have made tremendous progress in this area, work is still in early stages. Some of the underlying issues still being worked out are finding the optimal size for chunks of knowledge within a learning system, how knowledge should be sequenced, what the prerequisites for mastering a given chunk should be, how assessments can provide evidence of mastery of these chunks, and the nature of the decision rules that should drive movement through complex spaces of ideas. The organization of knowledge along these trajectories may depend on (1) the structure of the big ideas of the discipline and (2) cognitively what it takes to move from being a novice in a domain to becoming an expert who not only knows facts, but also can use and apply that knowledge in problem solving and in understanding related material. A further limitation is that most of the work in this area has been on mathematics and reading.

Conclusion

Technology shows great promise for helping shape and personalize learning experiences. Automated tutors can use the strategies of human tutors to scaffold, support, and accelerate learning while mastery-based content offers self-paced progression for students. Advances in the capabilities of technology to gather, store, and analyze data (US. Department of Education, 2012a) can help educators make better informed decisions as they attempt to match students with the most appropriate learning experiences. More specifically, ongoing formative assessment of students helps educators deliver specialized instructional content, such as narrative passages at a student's reading level, worked examples of mathematics problems, or leveled apps that students use during rotations in blended classrooms. Technology can also help organize content to support students in pursuing different pathways as they navigate tailored sets of resources to meet learning objectives. Educators should also be aware of the current limitations of technology and the ethical and legal considerations regarding accessibility and privacy and should be informed consumers as they make decisions about technology adoption and teacher professional development. Learners are complex, and nothing can replace the sophisticated understandings of students that teachers can develop; but wielded effectively, technology has the potential to enhance teacher understanding and decision making for personalizing learning.

5. Conclusions and Recommendations

This report is intended to support educators, education leaders, policy makers, technology developers, and researchers in becoming informed consumers and designers of new forms of technology-enabled personalized learning. The aim was to identify and learn from various personalized learning strategies currently being developed and implemented in classrooms, technology companies, and research institutions. There were widespread signs of promise—a new generation of technologies is creating unprecedented opportunities for personalization; schools, districts, and charter management organizations are making small and large-scale changes to promote personalized learning; and a growing research base is supporting the foundations of these approaches. At the same time, thought leaders indicated that this work is still in the early stages and that much remains to be done to ensure that approaches are designed and implemented in ways that are supported by research and in students' best interests. What follows are conclusions and recommendations to guide practitioners, policy makers, and researchers in designing, implementing, and enhancing personalized learning using technology.

Conclusions and Recommendations for Educators

The following conclusions and recommendations are for educational leaders who are designing or enhancing technology-enabled personalized learning approaches in their schools. They are intended to promote the development of implementation models that maximize benefits for students, teachers, principals, and institutions while strategically addressing common challenges.[5]

1. Learn from the agencies, organizations, and schools engaged in promoting personalizing learning using technology.

Educational leaders recommended learning from the successes and challenges of those who have already developed technology-enabled personalized learning approaches. This report presents learnings from cutting-edge innovators about how to define personalized learning (Chapter 2), essential elements of technology-enabled personalized learning environments (Chapter 3), and

[5] Educators must also be aware of their federal civil rights obligations to ensure equal access for all student populations, including students with disabilities. See the end of Chapter 1 for more information.

the roles that technology can play in personalizing learning (Chapter 4). Each chapter also describes some of the critical challenges, limitations, and needs for strategic supports. The following resources may prove helpful in the next steps of those implementing or considering implementing technology-enabled personalized learning:

- U.S. Department of Education
  - Race to the Top – District (RTT-D; http://www2.ed.gov/programs/racetothetop-district/index.html). The 2012 and 2013 district awardees are shown in Table 1, and recent case studies from RTT-D districts provide concrete depictions of what personalized learning looks like across schools and districts https://rttd.grads360.org/services/PDCService.svc/GetPDCDocumentFile?fileId=7452 (U.S. Department of Education, 2014b).
  - National Education Technology Plan 2010— *Transforming American Education: Learning Powered by Technology*, can be found at http://tech.ed.gov/wp-content/uploads/2013/10/netp2010.pdf (U.S. Department of Education, 2010b).
  - *Understanding the Implications of Online Learning for Educational Productivity* can be found at http://tech.ed.gov/files/2013/10/implications-online-learning.pdf (U.S. Department of Education, 2012b).
  - *Teachers' Ability to Use Data to Inform Instruction: Challenges and Supports* can be found at http://www2.ed.gov/rschstat/eval/data-to-inform-instruction/report.pdf (U.S. Department of Education, 2011).
  - The Privacy Technical Assistance Center (http://ptac.ed.gov/) website is a one-stop resource for education stakeholders to learn about data privacy, confidentiality, and security practices.
  - Documents from Russlynn Ali, Assistant Secretary for Civil Rights (May 26, 2011), address questions about the obligations of educational institutions with respect to civil rights laws that prohibit discrimination on the basis of disability (http://www2.ed.gov/about/offices/list/ocr/letters/colleague-201105-ese.html).
- The Next Generation Learning Challenges (http://nextgenlearning.org/).

Table 1. U.S. Department of Education Race to the Top – District Awardees

Information about the competition and winners can be found here: http://www2.ed.gov/programs/racetothetop-district/awards.html.

State	District(s)
Arkansas	Springdale Public Schools*
California	Galt Joint Union School District Lindsay Unified School District New Haven Unified School District
Colorado	St. Vrain Valley Schools
District of Columbia	KIPP DC
Florida	School Board of Miami-Dade County
Indiana	Metropolitan School District of Warren Township
Kentucky	Green River Regional Educational Cooperative (consortium) Kentucky Valley Educational Cooperative (consortium)*
Mississippi	Clarksdale Municipal School District*
North Carolina	Guilford County Schools Iredell-Statesville Schools
Nevada	Carson City School District
New York	Middletown City School District
South Carolina	Charleston County School District Clarendon County School District Two (consortium)*
Texas	Harmony Science Academy (Harmony Public Schools) Idea Public Schools Houston Independent School District*
Washington	Puget Sound Educational Service District (consortium)

* 2013 winners; all others are 2012 winners.

- The Software & Information Industry Association's (SIIA) Education Division (http://www.siia.net/blog/index.php/category/personalized-learning/).
- The International Association for K-12 Online Learning (iNACOL) (http://www.inacol.org/).
- The Re-Inventing Schools Coalition (http://www.reinventingschools.org/).
- EDUCAUSE (https://www.educause.edu/) provides resources and research summaries for higher education.

2. Make informed decisions about technology to support personalized learning, and ensure that the necessary technology infrastructure will be available.

Practitioners must look beyond surface descriptions of a product and make informed decisions about which personalized learning approaches are appropriate for their students' specific needs. Table 2 provides a checklist of questions to support informed decision making about technologies and approaches to personalize learning. A 2014 report from the U.S. Department of Education (2014d) presents additional questions and resources for building the infrastructure to support approaches like personalized learning. It is important that leaders clarify the higher level goals they wish to accomplish (e.g., greater equity, implementation of new standards, or increased student engagement) and articulate their vision of how technology will be used along with other elements of change to accomplish these goals. Educators also need to understand the technology itself and key issues such as what evidence is available about its effectiveness, how it will address the particular needs of their own student populations, what other kinds of services will need to be provided along with it, and how to ensure accessibility and privacy for all students.

The need for technical infrastructure was among the most cited challenges to implementing personalized learning opportunities. Setting up blended learning environments, for example, requires a sufficient number of devices, adequate bandwidth for connectivity, and places to charge mobile devices. Schools are dealing with these issues in a variety of ways. Some are seeking external funding from industry and government and resources from the nonprofit sector. Some have a policy that requires students to provide their own devices. Some schools are partnering with local organizations to get discounts for students to buy devices and receive home Internet access. Access to technology outside school can also be a component of personalized learning approaches that leverage the anytime, anywhere capabilities of online learning. Some schools are partnering with community organizations to provide centers where students can work online during out-of-school time.

Table 2. Checklist of Questions About Technology for Personalized Learning

These questions—rather than a rating system—are intended to help educational leaders refine a vision of what technology will enable and to highlight important information to gather from technology vendors before selecting products.

To clarify your vision for technology-enabled personalized learning in your school:

1. What goals do you expect to accomplish for students, teachers, and the school by adopting this technology?
2. What roles will technology play in tailoring learning? Automated adaptation of learning opportunities? Support for resource management? Support for integrating and using student data?
3. How do you want the classroom to be organized in terms of space, time, and educator roles? Will it be a blended learning model? If so, which kind—station rotation, lab rotation, etc.?
4. In what ways do you want students to empower students to exercise personal agency and responsibility for what they learn?
5. How will students with disabilities and special needs be provided access and support for working the technology?

To evaluate the technology and technology vendor with respect to your needs:

1. Does the technology support a particular pedagogical orientation? Is this orientation consistent with the types of learning opportunities you want to provide your students?
2. How well does the technology support students with disabilities and other special needs?
3. What kinds of teacher training are necessary to implement the system well? What kinds of professional supports does the vendor offer educators?
4. What are the technical requirements for implementing this technology? Does your school have sufficient infrastructure?
5. Is this technology interoperable with other data systems or technologies in your school? How will you handle integrating activities and data from multiple systems?
6. Are there any research or evaluation reports about the effectiveness of this technology? Are these findings applicable to your particular student population?
7. How does the company ensure data privacy and security? Do its services comply with all state and federal statutes?
8. What are the potential challenges and downsides of using this particular system?

To understand how the system works:

1. What is the role of the teacher in implementing this system in the classroom?
2. To what degree and in what ways can students make choices and self-regulate their own learning? Can they make choices that influence their own learning objectives, pathways, and/or pace? Can they seek help?
3. What types of data will be collected about students and how will the data be used by the technology, the teacher, and/or the student to tailor learning experiences?
4. What data are displayed on the product's dashboards for teachers, students, and administrators? Can the data be customized?
5. If the system is competency based, how do students demonstrate competency and advance to new content?
6. If applicable, how does the technology vendor determine what the learning trajectories should be? Does it use an empirical basis for this? Do the empirical data apply specifically to the types of students in your school?
7. Does the technology provide feedback about engagement and/or "early warning" indicators? Does it tell you when students are spending too much or too little time on activities or when they are not progressing at a pace that will enable them to finish the course within the academic term?
8. Does the system have ways for students to overcome frustration? Does it offer encouragement and reward persistence?

3. Support educators in shifting roles and developing new capacities.

Technology-enabled personalized learning models require teachers to adopt roles that are unfamiliar to many: differentiating instruction for individuals or groups, organizing a classroom to allow multiple simultaneous activities, using data to inform instructional decisions, and more extensive integration of technology, to name a few. Principals also need support as they enact new visions for their schools. In schools that are putting in place personalized learning opportunities, teachers also need clear guidelines for how to support students. They may also need to develop practices for using data to inform instruction, for example, through enhanced understanding of how to locate relevant data, understand what data signify and how to interpret data, select instructional approaches that address needs identified in the data, and frame instructionally relevant questions that can be addressed by the data (U.S. Department of Education, 2011). In addition to formal professional development opportunities, many leaders have found that facilitation of active professional communities is essential support for teachers as they navigate steep learning curves in implementing personalized learning strategies. Others roll out initial personalization strategies selectively, looking first for teachers with strong classroom management or technology skills and particularly seeking out teachers who are motivated and enthusiastic about trying new things. Several educators described their relative success at attending appropriately to all students with smaller class sizes along with additional support staff in their classrooms working with them to implement team or paired-teaching strategies. Teachers appreciated the latitude to spend more time with those students who most needed their help, while knowing that all other students were productively engaged.

Personalizing learning for teachers themselves is particularly important; teachers need to be exposed to what it is like to be a learner within the personalized learning model, and they also need individualized professional supports as they transition into their new roles and capacities.

4. Promote teaching practices and technologies that support students' productive engagement, self-regulated learning, and development of conceptual understanding.

When technology is a major aspect of the learning environment, educators need to be particularly attentive to ensure that students are productively engaged and self-regulating their learning. The following were some of the issues that came to the surface in the interviews:

- Students may not be ready for agency and choice.
- Students can avoid being challenged.
- Students can have greater opportunity to be unproductive.
- Automated adaptation can depersonalize learning by not being responsive to students' important emotional experiences—frustration, anxiety, boredom, and interest.
- New technologies can reinforce old pedagogies, such as rote learning and memorization.

Educators need to closely evaluate new technologies and approaches for their appropriateness to their particular student population, including students with disabilities and special needs. Educators should also consider the resources and supports from teachers and instructional aides that will be necessary to keep students productively engaged and on task. Educators seeking to support students' conceptual understanding, creativity, problem solving, and communication skills should make sure that the instructional systems they adopt support these kinds of learning. Without careful attention to the nature of learning activities, feedback, and assessment, the risk is that personalized learning will reinforce a focus on basic skills to the exclusion of deeper learning.

5. Consider implementing changes that might be necessary to address challenges of working with students learning at different paces.

When students work at their own pace, gaps can occur in the time different students take to master their learning goals. Students who are fast learners can cover much more content within the standard instructional time, but slower learners, required to demonstrate mastery before moving to new content, often need considerably more time than is usually allotted to work through the whole curriculum. Mastery learning can mean that struggling students will repeat some material multiple times, falling behind their peers in curriculum coverage. Educators must consider how additional supports, such as extra time and individualized attention from teachers, can be given to those students who need them.

Some CMOs are accommodating different paces, especially for students who struggle and need to catch up, by lengthening the school day, increasing the number of school days per year, providing support time on the weekends, and/or moving to a year-round schedule. Teachers' busy schedules always make the successful rollout of new initiatives challenging, even without increased instructional time. This is particularly true with the school models that require teachers to plan at the student or small-group level, to facilitate a variety of activities in any one class period, and to make data analysis a regular practice. Time for preparation, planning, and problem solving—both individual and collaborative—is essential. Schools are adopting various strategies, such as distributing responsibilities to educator specialists (e.g., focused on technology, instruction, teacher coaching, and the like) and decreasing class sizes so that teachers can concentrate on fewer students at a time.

6. Consider how leaders in all parts of the system can engage in continuous improvement efforts.

With the introduction of any initiative in schools, educators and administrators should expect to go through multiple cycles of program design, implementation, evaluation, and refinement. Some schools and educational organizations incorporate processes for administrators and teachers to evaluate the progress of their personalized learning initiatives and use formative evaluation findings as input to ongoing improvement efforts. For example, administrators may use student data and teacher observation data, along with information collected from multiple stakeholders (e.g., teachers, principals, parents, local policy makers) to identify successes,

obstacles, and solutions. They may focus on student achievement, effectiveness of technology, effectiveness of teacher professional development, teacher satisfaction, use of resources, and the like. Improvement processes may include briefing stakeholders on progress and working together with school staff to address issues that arise.

Conclusions and Recommendations for Policy Makers

Policy makers, especially at the state and local levels, can play critical roles in supporting practitioners' transition to personalized learning. The following recommendations address some high-level policy issues and some of the ways that policy makers at various levels can reduce barriers and promote personalized learning in schools. In addition, Bellwether Education Partners' recently released "policy playbook" provides 15 detailed recommendations for increasing supply and demand of personalized learning models and for addressing the broader policy context to reduce barriers to implementation (Chuong & Mead, 2014).[6]

1. Provide financial resources for start-up costs for the transition to personalized learning and ongoing continuous evaluation and improvement.

The transition to personalized learning approaches can require significant financial resources. Policy makers can make strong contributions to the implementation of these models by ensuring that schools have the resources needed for technology, data warehousing, teacher capacity, facilities, and evaluation. Requirements for hardware and software, teacher staffing and training, and often facilities improvements can be difficult to fit within existing school budgets. Schools need funds for start-up costs to design new models and establish the necessary infrastructure. Furthermore, as educational leaders make plans for continuous improvement efforts, policy makers can provide resources for external evaluations that provide formative feedback that schools can use to refine iteratively their implementation of personalized learning.

2. Promote investment in high-quality, effective, integrated, and secure technology systems to support personalized learning.

Policy makers can create incentives for schools, researchers, and technology developers to create and implement high-quality personalized learning supports. For example, the Department's supplemental priorities for discretionary grant programs already prioritize programs that promote personalized learning (U.S. Department of Education, 2014a, 79 FR 73425). Also, states or districts can develop criteria for evaluating technology vendor quality, which could assist schools in navigating the complex technology industry while at the same time giving technology vendors incentives to provide resources that meet quality criteria. States and districts can also help schools with the challenges of integrating data across institutional systems and technology platforms by providing incentives to make data sets accessible, interoperable, and linkable while

[6] State and local policy makers, in considering changes that reduce barriers and promote personalized learning that might impact the use of federal grant funds, will have to ensure continued compliance with federal requirements.

maintaining security and ensuring students' privacy in compliance with state laws and FERPA, COPPA, and PPRA. For example, policy makers can assist in the development of standards that technology vendors must follow in working with student data (U.S. Department of Education, 2009a).

3. Support more flexible accountability structures compatible with competency-based learning models and innovations in educational approaches.

A recurring challenge for schools adopting personalized learning approaches was supporting students working at different paces toward their academic goals. For example, a challenge for high schools in implementing competency-based learning approaches in states like California is that students need to demonstrate completion of specific high school courses to be eligible to apply to the states' 4-year higher education institutions. Students who need more time to master course content may drop out before completing the full required college-ready program. Another recurring challenge is giving teachers flexibility in their restructured roles when evaluation systems incentivize traditional instructional approaches.

Policy makers can establish structures that allow for the flexibility needed to empower struggling students, restructure evaluation frameworks and incentive systems to promote new classroom teacher roles, and make provisions for schools to innovate. Across interviews, some of the approaches included modifying policies about staffing and class size and modifying seat-time requirements to support competency-based learning (see Taylor, White & Toch, 2015). Policy makers in several districts provided the resources for small "innovation zones" in which schools or districts had a concentrated period of time to work with a small subset of their population to begin designing and implementing innovative approaches with less stringent accountability structures. This flexibility helped them make the transition to a new approach that could then be scalable.

Conclusions and Recommendations for Researchers

These recommendations are intended for researchers who want to advance the knowledge base for supporting personalized learning models. Effective personalized learning requires a range of expertise—technological, instructional, and organizational—as well as a range of theoretical orientations across disciplines of educational research and the learning sciences. A strong general recommendation from researchers was that research on personalized learning leverage all these perspectives together.

1. Conduct rigorous field-based research to examine the impacts of personalized learning interventions and identify promising practices.

Although there is widespread interest in and increasing implementation of personalized learning approaches, personalized learning is still new and little clear evidence exists about its short- and long-term impacts across the range of K–12 disciplinary content areas and student populations. There is a strong need for rigorous field-based randomized experiments and quasi-experimental

designs that meet the standards for What Works Clearinghouse (U.S. Department of Education, 2014c) and for complementary research that relies on newer methods for collecting evidence in technology-rich environments (U.S. Department of Education, 2013). Researchers need to examine the impacts at multiple levels of the education system, including the intended and unintended effects that occur when districts and schools reorganize to adopt personalized learning models. There is a need to look at multiple outcomes—not just results on standardized assessments. For example, are students developing higher order thinking skills such as problem solving and application? Are they engaged in preparation for future learning and able to transfer conceptual understanding? Are they developing motivation and interest in school? Are metacognitive and noncognitive capacities being developed when students interact with learning software? How do adaptive interventions affect those processes? Are technologies eliminating productive struggle or the need for students to overcome learning challenges without assistance? Are there impacts on long-term educational attainment, such as graduation rates and college readiness? Are the needs of all student populations, including students with disabilities, being addressed appropriately? There is also a need to examine impacts on teachers, for example, on their professional knowledge, teaching practices, and retention in the workforce.

It is also important for researchers to seek out educators who are implementing personalized learning models well to identify best practices. Many pockets of innovation exist within schools and educational organizations. Researchers should search for a range of effective models and do ethnographic studies exploring the landscape of successful personalized learning practices. What are the practices? What kinds of professional development are leading teachers to adopt these practices? When do students actually feel like something is personalized and shift their attitudes toward schooling? How are educators talking about personalized learning? What parts of school districts are talking about it? Are fewer students falling through the cracks? What are the barriers and facilitators to scale of technology? Questions such as these can help educators think critically about the organizational and teacher training needs that can come with implementing personalized learning models at scale. Researchers can also work with schools and districts to help them use their data to make better decisions about tools and practices that work for their students.

2. Develop research-based frameworks to clarify and unify concepts that structure and inform personalized learning models.

A major challenge in personalized learning approaches is the diversity of perspectives and lack of clear, unifying research-based frameworks for understanding what personalized learning is and how it can be implemented in various contexts. Researchers can play an important role in teasing apart the specific strategies that are critical to practice and construct holistic personalized learning frameworks. For example, collaborative partnerships, working groups, professional conferences, and peer-reviewed publications should be geared to identify individual components and explain how these relate to each other to describe evidence-based personalized learning models.

3. Build and expand the science behind learning trajectories, adaptation of learning experiences, assessment during learning processes, and provision of actionable data for teachers and students.

Personalization works through tailoring cycles in which learning data are collected, these data are interpreted, and the learning experience is adapted. Researchers have noted that the theoretical principles underlying how those assessments and adaptations should be made are in rudimentary stages of development. Some of the underlying issues are finding the optimal size for chunks of knowledge within a learning system, how knowledge should be sequenced, what the prerequisites for mastering a given chunk should be, how assessments can provide evidence of mastery of these chunks, and the nature of the decision rules that should drive movement through complex spaces of ideas. Cognitive scientists and technology developers approach these issues through concurrent methods of mapping knowledge domains, using learning analytics/educational data mining approaches to optimize learning sequences, and understanding cognitive, affective, and motivational processes that unfold during learning. A related issue is that most of the work in this area has been on mathematics and reading. A strong need remains to examine learning trajectories for other subjects, such as foreign language, writing, science, and social studies.

Closely tied to understanding learning trajectories are issues of assessment. The need exists for valid, reliable assessments that can provide useful information about what students know and are able to do with respect to particular learning trajectories. Researchers also emphasized the importance of understanding the affective experiences that can be deeply intertwined with learning, such as boredom, frustration, anxiety, and interest. While students' self-reports of these experiences have shown little utility in many instructional contexts, researchers are beginning to develop automated ways within digital learning environments to make inferences about these states and explore their use, in combination with data about content understandings and misconceptions, to inform instructional adaptations. Much of this work is blurring the lines between learning experiences and assessment. Multiple adaptive technologies, such as intelligent tutors and digital games, are creating opportunities for assessing students' knowledge, skills, and abilities as they engaged in learning activities (Shute & Ventura, 2013). Subsequent learning experiences that are matched to students based on detailed data concerning what they know and how they approach solving problems could lead to increasingly tailored experiences.

Furthermore, as the push to better measure student learning using data from online environments increases, more work needs to be done attending to the needs of students with disabilities. Research should address how useful and productive inferences can be made about students with disabilities on the basis of data collected within these systems, as well as how to reduce any barriers presented by the technology itself as students with disabilities engage in digital learning opportunities.

It is also important to address the challenges of integrating the vast amount of educational data in a meaningful and actionable way for teachers and students. New research should leverage the extensive literature base on data-driven decision making in the personalized learning context, informed by multidisciplinary expertise from the typically disparate worlds of information visualization and instructional decision making. Research is needed to clarify what data teachers may attend to and how data patterns can be simplified to make them more actionable.

Researchers can also address questions about how to empower students in using their own data to improve their learning and career pathways.

4. Translate findings and provide research-based guidance about how to implement effective personalized learning models with fidelity and overcome potential implementation challenges.

Researchers should translate and disseminate findings about impacts and best practices so that practitioners know how to implement evidence-based personalized learning. Researchers in universities and nonprofit organizations are well positioned to explore the issues identified in the implementation of personalized learning to help others adopt effective research-based models with fidelity. This work should also address the potential drawbacks and ways to implement strategic supports for effective implementation. For example, many students may require extra time and individualized attention to stay on task and learn, educators need to ensure that learning goals address high-level thinking skills, teachers need support in optimizing their use of time, and educators need to ensure that learning approaches continue to draw on the support that can come from teachers and peers. Some important avenues of dissemination are providing assistance to local administrators, writing articles for practitioner-oriented journals and presenting at practitioner-oriented conferences, working collaboratively with teacher educators, and informing policy makers about important research findings (Anderman, 2011).

References

American Institutes of Research. (n.d.). *RTI glossary of terms*. Retrieved from http://www.rti4success.org/resources/rti-glossary-terms

American Institutes of Research. (2013). Are personalized learning environments the next way of K-12 education reform? Washington, DC: Author.

Anderman, E. M. (2011). Education psychology in the twenty-first century: Challenges for our community. *Educational Psychologist, 46*(3), 185–196.

Black, P., & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education, 5*(1), 7–74.

CFY. (n.d.). *Our approach.* Retrieved from http://cfy.org/what-we-do/our-approach/

Childress, S. (2014). *College ready: Next generation learning strategy overview*. Seattle, WA: Bill & Melinda Gates Foundation.

Childress, S., & Benson, S. (2014). Personalized learning for every student every day. *Phi Delta Kappan, 95*(8), 33–38.

Chuong, C., & Mead, S. (2014). *A policy playbook for personalized learning: Ideas for state and local policymakers*. Bellwether Education Partners. Retrieved from http://bellwethereducation.org

Coburn, C. E., & Turner, E. O. (2011). Research on data use: A framework and analysis. *Interdisciplinary Research & Perspective, 9*(4), 173–206.

Collins, A., & Halverson, R. (2009). *Rethinking education in the age of technology: The digital revolution and schooling in America*. New York, NY: Teachers College Press.

Connor, C. M., Piasta, S. B., Fishman, B., Glasney, S., Schatschneider, C., Croqe, E., Underwood, P., & Morrison, F. J. (2009). Individualizing student instruction precisely: Effects of child x instruction interactions on first graders' literacy development. *Child Development, 80*(1), 77–100.

Cordova, D. I. L., & Lepper, M. R. (1996). Intrinsic motivation and the process of learning: Beneficial effects of contextualization, personalization, and choice. *Journal of Educational Psychology, 88*(4), 715–730.

Cuban, L. (1986). *Teachers and machines: The classroom use of technology since 1920*. New York, NY: Teachers College Press.

Cuban, L. (2001). *Oversold and underused: Computers in the classroom*. Cambridge, MA: Harvard University Press.

Darling-Hammond, L., & Friedlaender, D. (2008). Creating excellent and equitable schools. *Educational Leadership, 65*(8), 14–21.

Dignath, C., Buettner, G., & Langfeldt, H. P. (2008). How can primary school students learn self-regulated learning strategies most effectively? *Educational Research Review, 3*(2), 101–129.

Dweck, C., Walton, G. M., & Cohen, G. L. (2011). *Academic tenacity: Mindsets and skills that promote long-term learning*. Seattle, WA: Bill & Melinda Gates Foundation.

Education Growth Advisors. (2013). *Learning to adapt: Understanding the adaptive learning supplier landscape*. Retrieved from http://edgrowthadvisors.com/research-paper-1/

Friedlaender, D., Darling-Hammond, L., Andre, A., Lewis-Charp, H., McCloskey, L., Richardson, N., & Vasudeva, A. (2007). *High schools for equity: Policy supports for student learning in communities of color*. Stanford, CA: School Redesign Network at Stanford University.

Fuchs, D., & Fuchs, L. (2006). Introduction to Response to Intervention: What, why, and how valid is it? *Reading Research Quarterly, 41*(1), 93–99.

Glowa, L. (2013). *Re-engineering information technology: Design considerations for competency education*. *A Competency Works issue brief*. International Association for K–12 Online Learning. Retrieved from http://www.competencyworks.org/wp-content/uploads/2013/02/iNACOL_CW_IssueBrief_ReEngineeringCompEd_final.pdf

Graf, S. K., & Kinshuk, C. (2012). Personalized learning. In N. M. Seel (Ed.), *Encyclopedia of the sciences of learning*. New York, NY: Springer.

Hamilton, L., Halverson, R., Jackson, S., Mandinach, E., Supovitz, J., & Wayman, J. (2009). *Using student achievement data to support instructional decision making*. Washington, DC: National Center for Education Evaluation and Regional Assistance, Institute of Education Sciences, U.S. Department of Education. Retrieved from http://ies.ed.gov/ncee/wwc/publications/practiceguides/

Heilman, M., Collins-Thomspon, K., Callan, J., Eskenazi, M., Juffs, A., & Wilson, L. (2010). Personalization of reading passages improves vocabulary acquisition. *International Journal of Artificial Intelligence in Education 20,* 73–98.

Hemelt, S. W., Roth, K. B., & Eaton, W. W. (2013). Elementary school interventions: Experimental evidence on postsecondary outcomes. *Educational Evaluation and Policy Analysis, 35*(4), 413–436. doi:10.3102/0162373713493131

Hidi, S. H., & Harackiewicz, J. M. (2000). Motivating the academically unmotivated: Critical issue for the 21st century. *Review of Educational Research, 70*(2), 151–179.

Hidi, S. H., & Renninger, K. A. (2006) The four-phase model of interest development. *Educational Psychologist, 41*(2), 111–127.

Ito, M., Gutierrez, K., Livingstone, S., Penuel, B., Rhodes, J., Salen, K., Schor, J., Sefton-Green, J., & Watkins, S. C. (2013). *Connected learning: An agenda for research and design*. Irvine, CA: Digital Media and Learning Research Hub.

Koedinger, K. R., Booth, J. L., & Klahr, D. (2013). Instructional complexity and the science to constrain it. *Science, 342*, 935–937.

Koedinger, K. R., & Corbett, A. (2006). Cognitive tutors: Technology bringing learning sciences to the classroom. In K. R. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 61–78). New York, NY: Cambridge University Press.

Maehr, M. L., & Zusho, A. (2009). Achievement goal theory. In K. R. Wentzel & A. Wigfield (Eds.), *Handbook of motivation at school*. New York, NY: Routledge.

Means, B., Bakia, M., & Murphy, R. (2014). *Learning online: What research tells us about whether, when and how*. New York, NY: Routledge.

Murphy, R., Gallagher, L., Krumm, A., Mislevy, J., & Hafter, A. (2014). *Research on the use of Khan Academy in schools*. Menlo Park, CA: SRI International. Retrieved from http://www.sri.com/sites/default/files/publications/khan-academy-implementation-report-2014-04-15.pdf

National Research Council. (2001). *Knowing what students know*. Washington DC: National Academy Press.

Natriello, G. (Ed.). (2013). *Adaptive educational technologies: Tools for learning, and for learning about learning.* Washington, DC: National Academy of Education. Retrieved from http://www.naeducation.org/cs/groups/naedsite/documents/webpage/naed_085633.pdf

Patrick, S., Kennedy, K., & Powell, A. (2013). *Mean what you say: Defining and integrating personalized, blended and competency education*. Vienna, VA: iNACOL.

Piety, P. J. (2013). *Assessing the educational data movement*. New York, NY: Teachers College Press.

Shute, V. J., & Ventura, M. (2013). *Measuring and supporting learning in games: Stealth assessment*. Cambridge, MA: MIT Press.

Shute, V. J., & Zapata-Rivera, D. (2012). Adaptive educational systems. In P. Durlach (Ed.), *Adaptive technologies for training and education* (pp. 7–27). New York, NY: Cambridge University Press.

Spillane, J. P., & Miele, D. B. (2007). Evidence in practice: A framing of the terrain. In P. A. Moss (Ed.), *Evidence and decision making* (pp. 46-73). New York, NY: The National Society for the Study of Education.

Staker, H., & Horn, M. B. (2012). Classifying K-12 blended learning. *Innosight Institute.* Retrieved from: http://files.eric.ed.gov/fulltext/ED535180.pdf

Strecher, V. J., Kreuter, M., Den Boer, D. J., Kobrin, S., Hospers, H. J., & Skinner, C. S. (1994). The effects of computer-tailored smoking cessation messages in family practice settings. *Journal of Family Practice, 39*(3), 262–270.

Tomlinson, C. A., Brighton, C., Hertberg, H., Callahan, C. M., Moon, R. M., Brimijoin, K., Conover, L. A., & Reynolds, T. (2003). Differentiating instruction in response to student

readiness, interest, and learning profile in academically diverse classrooms: A review of literature. *Journal for the Education of the Gifted, 27*(2/3), 119–145.

U.S. Department of Education. (2009a). *Implementing data-informed decision making in schools: Teacher access, supports and use*. Retrieved from http://tech.ed.gov/research/

U.S. Department of Education. (2009b). *Use of education data at the local level: From accountability to instructional improvement*. Washington, DC: Author.

U.S. Department of Education. (2010a). *Evaluation of evidence-based practices in online learning.* Retrieved from http://www2.ed.gov/rschstat/eval/tech/evidence-based-practices/finalreport.pdf

U.S. Department of Education. (2010b). *Transforming American education: Learning powered by technology*. Retrieved from http://tech.ed.gov/wp-content/uploads/2013/10/netp2010.pdf

U.S. Department of Education. (2011). *Teachers' ability to use data to inform instruction: Challenges and supports.* Retrieved from http://www2.ed.gov/rschstat/eval/data-to-inform-instruction/report.pdf

U.S. Department of Education. (2012a). *Enhancing teaching and learning through educational data mining and learning analytics: An issue brief*. Retrieved from http://tech.ed.gov/wp-content/uploads/2014/03/edm-la-brief.pdf

U.S. Department of Education. (2012b). *Understanding the implications of online learning for educational productivity.* Retrieved from http://tech.ed.gov/files/2013/10/implications-online-learning.pdf

U.S. Department of Education. (2013). *Expanding evidence approaches for learning in a digital world*. Retrieved from http://tech.ed.gov/wp-content/uploads/2014/11/Expanding-Evidence.pdf

U.S. Department of Education. (2014a). *Secretary's final supplemental priorities and definitions for discretionary grant programs*. Retrieved from http://www.gpo.gov/fdsys/granule/FR-2014-12-10/2014-28911

U.S. Department of Education. (2014b). *Personalized learning in progress: Case studies of four Race to the Top – District grantees' early implementation*. Washington, DC: Author.

U.S. Department of Education. (2014c). *What Works Clearinghouse: Procedures and standards handbook version 3.0.* Retrieved from http://ies.ed.gov/ncee/wwc/DocumentSum.aspx?sid=19

U.S. Department of Education. (2014d). *Future ready schools: Building technology infrastructure for learning.* Retrieved from http://tech.ed.gov/wp-content/uploads/2014/11/Future-Ready-Schools-Building-Technology-Infrastructure-for-Learning-.pdf

U.S. Department of Education. (2014e). *Learning technology effectiveness.* Retrieved from http://tech.ed.gov/wp-content/uploads/2014/11/Learning-Technology-Effectiveness-Brief.pdf

VanLehn, K. (2011). The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems. *Educational Psychologist, 46*(4), 197–221.

Walkington, C., Petrosino, A., & Sherman, M. (2013). Supporting algebraic reasoning through personalized story scenarios: How situational understanding mediates performance and strategies. *Mathematical Thinking and Learning, 15*(2), 89–120.

Winne, P. H. (2011). A cognitive and metacognitive analysis of self-regulated learning. In B. J. Zimmerman & D. H. Schunk (Eds.), *Handbook of self-regulation of learning and performance* (pp. 15–32). New York, NY: Routledge.

Wolf, M. (2010). Innovate to educate: System [re]design for personalized learning. *A Report from the 2010 Symposium*. Washington, DC: Software & Information Industry Association.

Wolf, M. A., & Schneiderman, M. (2014). *A national summit on technology-enabled personalized learning*. Paper presented at the Technology-Enabled Personalized Learning Summit, Raleigh, NC.

Yeager, D. S., & Dweck, C. S. (2012). Mindsets that promote resilience: When students believe that personal characteristics can be developed. *Educational Psychologist, 47*(4), 302–314.

Yeager, D. S., & Walton, G. M. (2011). Social-psychological interventions in education: They're not magic. *Review of Educational Research, 81*(2), 267–301.

Yeager, D. S., Walton, G., & Cohen, G. L. (2013). Addressing achievement gaps with psychological interventions. *Phi Delta Kappan, 94*, 62–65.

Young, V. M., & Kim, D. H. (2010). Using assessments for instructional improvement: A literature review. *Education Policy Analysis Archives*, *18*(19), 1–36.

Zimmerman, B. J., & Compillo, M. (2003). Motivating self-regulated problem solvers. In J. E. Davidson & R. Sternberg (Eds.), *The nature of problem solving*. New York, NY: Cambridge University Press.

SRI Education™

A DIVISION OF SRI INTERNATIONAL

SRI Education, a division of SRI International, is tackling the most complex issues in education to identify trends, understand outcomes, and guide policy and practice. We work with federal and state agencies, school districts, foundations, nonprofit organizations, and businesses to provide research-based solutions to challenges posed by rapid social, technological and economic change. SRI International is a nonprofit research institute whose innovations have created new industries, extraordinary marketplace value, and lasting benefits to society.

Silicon Valley

(SRI International Headquarters
333 Ravenswood Avenue
Menlo Park, CA 94025
+1.650.859.2000

education@sri.com

Washington, D.C.

1100 Wilson Boulevard, Suite 2800
Arlington, VA 22209
+1.703.524.2053

www.sri.com/education