NEPC

NATIONAL EDUCATION POLICY CENTER

Personalized Instruction

New Interest, Old Rhetoric, Limited Results, and the Need for a New Direction for Computer-Mediated Learning

Noel Enyedy

University of California at Los Angeles

November 2014

National Education Policy Center

School of Education, University of Colorado Boulder
Boulder, CO 80309-0249
Telephone: (802) 383-0058
Email: NEPC@colorado.edu
http://nepc.colorado.edu

This is one of a series of briefs made possible in part by funding from
The Great Lakes Center for Education Research and Practice.

GREAT LAKES CENTER
FOR EDUCATION RESEARCH & PRACTICE
http://www.greatlakescenter.org
GreatLakesCenter@greatlakescenter.org

Briefs published by the National Education Policy Center (NEPC) are blind peer-reviewed by members of the Editorial Review Board. Visit http://nepc.colorado.edu to find all of these briefs. For information on the editorial board and its members, visit: http://nepc.colorado.edu/editorial-board.

Publishing Director: **Alex Molnar**

Suggested Citation:

Enyedy, N. (2014). *Personalized Instruction: New Interest, Old Rhetoric, Limited Results, and the Need for a New Direction for Computer-Mediated Learning*. Boulder, CO: National Education Policy Center. Retrieved [date] from http://nepc.colorado.edu/publication/personalized-instruction.

Personalized Instruction: New Interest, Old Rhetoric, Limited Results, and the Need for a New Direction for Computer-Mediated Learning

By Noel Enyedy, University of California at Los Angeles

Executive Summary

There has been a renewed interest in and enthusiasm for online learning and computerized instruction. One gets a sense of déjà vu when reading today's educational blogs and policy documents, which are recycling the same arguments for computerized instruction that appeared in the 1980s. But in the more than 30 years since the personal computer and computer-assisted instruction entered K-12 education, not much has changed. Computers are now commonplace in the classroom, but teaching practices often look similar, as do learning outcomes. This raises two questions: What has changed to get people excited about online learning? And is this revival of enthusiasm warranted?

It seems that the pace of technological advancement, combined with the clear success stories of how technology has improved productivity in other sectors, is leading policymakers and educators alike to take another look at computers in the classroom, and even at computers *instead of* classrooms. In particular, advances in computational power, memory storage, and artificial intelligence are breathing new life into the promise that instruction can be tailored to the needs of each individual student, much like a one-on-one tutor. The term most often used by advocates for this approach is "Personalized Instruction."

However, despite the advances in both hardware and software, recent studies show little evidence for the effectiveness of this form of Personalized Instruction. This is due in large part to the incredible diversity of systems that are lumped together under the label of Personalized Instruction. Combining such disparate systems into one group has made it nearly impossible to make reasonable claims one way or the other. To further cloud the issue, there are several ways that these systems can be implemented in the classroom. We are just beginning to experiment with and evaluate different implementation models—and the data show that implementation models matter. How a system is integrated into classroom routines and structures strongly mediates the outcomes for students. In light of recent findings, it may be that we need to turn to new ways of conceptualizing the role of technology in the classroom—conceptualizations that do not assume the computer will provide direct instruction to students, but instead will serve to create new opportunities for both learning and teaching.

Therefore, it is recommended that:

- Education policymakers should continue to invest in technology but should be wary of advocacy promoting computerized instruction to an extent that oversteps the current research. Policymakers should pursue an incremental path with technology.

- Policymakers and researchers should clearly distinguish among key systemic features of technologies in use. "Personalized Instruction" is too broad and vague an umbrella term to allow for meaningful evaluation or to guide policy.

- Researchers should design studies focused on the K-12 context, because much available evidence to date has been extrapolated from studies done at the undergraduate and professional levels, where developmental and motivational factors differ.

- Setting aside the controversy surrounding national academic standards, where academic standards are in place, educators adopting instruction via technology should insist that developers provide software aligned with the standards. In one implementation study where standards were adopted,[1] 66% of the teachers reported the lack of the system's alignment with standards as a barrier to effective implementation. Adopters might also consider seeking software that reflects national assessment systems being developed (such as the Smarter Balanced Assessments), so that instructional systems parallel accountability systems and can possibly alleviate some of the onerous and time-consuming aspects of testing to the high standards set by the Common Core and Next Generation Science Standards.

- Policymakers should encourage more partnerships among developers, educational researchers and teachers. Such partnerships have great potential to produce systematic and rigorous evidence of what works and what doesn't, including studies that take into account the various combinations of technical features, pedagogical approaches and implementation models. We cannot trust market forces alone to sort out which systems are effective.

- Administrators must ensure that investments in technological infrastructure and software licensing are accompanied by substantive professional development for teachers in order to provide them with skills that have not historically been in the teacher's toolbox. Particularly important will be providing teachers with practice using technological data on student performance to guide instructional decisions for individual students.

- All stakeholders should refrain from assuming that Personalized Instruction is the only model for computers in the classroom and be open to investigating new models integrating technology into the learning process.

Personalized Instruction: New interest, old rhetoric, limited results, and the need for a new direction for computer-mediated learning

> Harnessing the power of digital technology is central to improving our education system and our global competitiveness. In the Internet age, every student in America should have access to state-of-the-art educational tools, which are increasingly interactive, individualized and bandwidth-intensive. The Federal Communications Commission shares the President's commitment to seizing the opportunities of digital learning.
>
> ***Tom Wheeler, FCC Chairman 2014***

Introduction

Computational technology has transformed almost every aspect of our lives in the United States. Commerce, transportation, agriculture, health services, personal communication—it is hard to think of any sector of our lives that has not been significantly changed through the integration of computers—except, that is, the teaching and learning enterprise of K-12 education. Here technology has been utilized—you will see computers in the classroom, and it is not uncommon to see a digital whiteboard at the front of the room—but it has not transformed the basic formula of how children are taught. Instead, for the vast majority of K-12 schools technology has been tacked onto the basic framework of instruction[2]. Teachers use PowerPoint lectures instead of chalkboards. Students use the web and digital archives instead of encyclopedias and other print-based sources for their research. But the basic formula of both traditional and computerized instruction has been "I, we, you,"[3] where the teacher (or computer) tells the student something, followed by a worked-out example gone over together, and ending with independent student practice. Everything we know about teaching and learning tells us that this formula is flawed and not working.[4] While the way we teach is not the only problem facing our schools, the dominant pedagogy used in many our nation's schools is in need of transformation, and many have looked to technology as the leading edge of that change. However, although there are exceptions, the introduction of personal computers into classrooms in the 1980s merely resulted in computers being bolted on to this sequence and not used to transform the teaching and learning enterprise as promised.[5]

Despite its history of unfulfilled promises, educational technology retains strong support of federal and local policymakers. As the opening quote by FCC Chairman Tom Wheeler indicates, the Obama administration, like its predecessors, has a strong commitment to investing in digital technologies for education. For example, President Obama recently announced close to $3 billion in funding from the Federal Communications Commission and several private technology companies for his ConnectEd initiative, which aims to close the technology gap in schools. This included $750 million in commitments from companies such as Apple, Microsoft, AT&T, Sprint and Verizon. ConnectEd, in partnership with these companies, hopes to transform the country's educational system by improving broadband connectivity to classrooms and libraries; providing increased access for teachers and students to "digital learning resources at any time inside and outside of the classroom"; ensuring that every educator in America receives support and training to use technology to help improve student outcomes; and, increasing the availability of high-quality digital learning resources and materials for students and teachers.

Additionally, investment in educational technology is embedded and earmarked throughout the Department of Education budget. This is true even for programs that on their face have nothing to do with educational technology. For example, in the federal government's Effective Teachers and Leaders State Grants, recipient states are directed to have some portion of the funds set aside for, or are to give priority to, programs that aim to "transform teaching and learning" through technology.[6]

Finally, President Obama has advocated for the creation of a new agency, modeled after DARPA, called Advanced Research Projects Agency for Education (ARPA-Ed). ARPA-Ed's task will be to fund projects undertaken by industry, universities, or other innovative organizations based on their potential to create a dramatic breakthrough in learning and teaching. The President's 2013 budget request of $90 million is in recognition of "the need for an integrated and thoughtful approach to technology by incorporating it throughout our programs, as outlined in the Administration's *Blueprint for the Reform of the Elementary and Secondary Education Act (ESEA)*."[7]

In this brief I will first outline the range of meanings that the term Personalized Instruction has taken on, identifying those aspects of online and computerized instruction that are beyond the limits of this review. I will then review the currently available data on student outcomes with a focus on large-scale evaluation studies and meta-analyses. Next, I will briefly address the costs associated with Personalized Instruction and how it varies depending on the implementation model and the school or district's current technological infrastructure. Finally, I will propose that what is needed is a new model to steer our investment in classroom technologies. It is difficult to draw any firm conclusions based on existing data—but it is also clear that proponents of technological infusion into education are undaunted and will continue to exert pressure. Therefore, I offer recommendations that may help chart a productive path forward.

Why the Renewed Interest in Educational Technology Today?

The mission of ARPA-Ed is telling, and points to why there is renewed interest in educational technology today, despite its disappointing history. ARPA-Ed is specifically interested in funding "Personalized Instruction," which generally is intended to mean instruction tailored to each individual student's needs. Proponents describe it as an instructional model in direct opposition to the assumed one-size-fits-all model in traditional schools. While this sounds straightforward, there are a variety of ways to personalize instruction, and different interpretations of personalization can lead to dramatically different technological systems with significantly different learning outcomes.

It is critical to note that "Personalized Instruction" is not the same as "personalized learning," even though promoters and vendors of technological systems often use the terms interchangeably. Personalized instruction focuses on tailoring the pace, order, location, and content of a lesson uniquely for each student—as when a software program introduces a quiz at some point during instruction and then, based on the student's score, either presents the student with new material or with a review of material not yet mastered. It is a rebranding of the idea of individualized instruction first promoted in the 1970s, before the widespread availability of personal computers.

Personalized learning, on the other hand, places the emphasis on the process of learning as opposed to attending exclusively to the delivery of content. Personalized learning refers to the ways teachers or learning environments can vary the resources, activities, and teaching techniques to effectively engage as many students as possible—as when, for example, students with a stronger intuitive understanding of the topic are assigned to small groups and given a challenging task to independently extend their understanding while the teacher concurrently works directly with a small group of students who have less prior knowledge of the topic. This interpretation of "personal" does not imply that each student receives a unique educational experience, but instead that students are provided with multiple entry points and multiple trajectories through a lesson.

Many of the current discussions of Personalized Learning are beginning to come to grips with the diversity of ways that learning can be personal, but still tend to conflate Personalized Instruction with Personalized Learning. For example, Education Week published a working definition of Personalized Learning[8]. Their definition, borrowed mostly from iNACOL[9], focuses on constructing learner profiles from data generated within the system. They then use this data to construct individualized paths through the provided materials. Students may move through this material at their own pace. They also note that this system will require schools to rethink how space and staff are used to support instruction. This working definition, however, focuses on tailoring the delivery of content and Personalized Instruction would be a more apt term. It is not that Personalized Instruction and Personalized Learning are incompatible, but including so many different ideas under one heading makes it difficult to understand what exactly is being offered. Because the vast majority of the systems on the market today fall in the category of Personalized Instruction (tailoring the pace, order, location, and content for individual students), this brief limits itself to reviewing the merits and properties of that approach: the following examination is of Personalized Instruction, not personalized learning. Even within this narrow category, there are many ways to design instruction and many ways to embed it into the larger pedagogies of a school or district.

Before examining this varied landscape, it is important to ask *What is at stake in the latest push to integrate digital technologies into the K-12 classroom?* The perennial hope for the computerization of teaching is that digital technologies can be effective and cost effective. But is that hope realistic? To what degree and in what ways? What is the true potential of Personalized Instruction? And what are the pitfalls?

Personalized instruction is touted as an efficient alternative to our current educational practices and organizations. And there is plenty of room to critique our current practice[10]. Since the 1970s scholars and politicians alike have noted that our public educational system was designed in the early 20th century around the metaphor of a factory. The goal was to produce students with a standardized set of skills and knowledge as efficiently as possible. As a result instruction was likewise standardized and broken down into age-banded, sequenced content. The practical work of teaching was positioned as part of the larger educational machine, and teachers were tasked with delivering instruction and advancing those students/products that passed inspection to the next grade. However, since the 1980s scholars and politicians alike have noted that the factory model no longer fits with our current economic needs[11]. While it is true that the largest sector of our economy is in low-wage, service-related jobs, the highest paid positions are what have been termed the "knowledge workers"[12] or "symbolic analysts"[13]—positions that value creativity, problem solving, and divergent thinking. Social mobility, especially for those who have historically been underserved by our current educational system, depends, at least in part, on transforming our current practice.

There is so much variability in features and models for implementation that it is impossible to make reasonable claims about the efficacy of Personalized Instruction as a whole.

Critiques of the factory model were used to bolster the case for computerized Personalized Instruction during the 1980s, and the same rhetoric has recently resurfaced in support of today's incarnation of Personalized Instruction. The typical argument for Personalized Instruction is that because technology has transformed the business sector and led to the need for a new type of worker, technology must also transform the educational system. Proponents insist that the computer should not simply be integrated into traditional models of instruction; instead, using the personal computer as the new metaphor for how education can be organized, proponents argue that the educational enterprise must be reorganized to take advantage of the latest capabilities of digital technologies—personalized, networked, anytime, anywhere instruction.

However, other scholars remind us that preparing students for successful participation in the economy is not the only role of public education.[14] Public education also has a critical commitment to developing an informed and engaged citizenry who can effectively participate in American democracy and ensure its future. The factory model, of course, fosters conformity towards a predetermined end rather than critical thinking and independent agency, and therefore it is ill-suited for the aims of democratic education. As we move forward and away from that model, an important question to keep in mind for every instructional innovation will be to what extent, and with what degree of effectiveness, a new model will address the foundational goal of education for democratic citizenry.

Thus, determining whether Personalized Instruction might be the best way to improve public education is a complex task involving multiple facets, not all of which (like a disposition for engaged citizenship) are readily accessible. Still, the rapid advance of technology into the field of education requires assessment of as many facets as possible. To begin, we need to better understand: what Personalized Instruction means in practice; whether it improves student outcomes; how cost effective it may be when estimates include hidden or non-monetary costs; and how well it addresses the goals, values and commitments of a publicly funded system in a democracy. We should also consider whether the personal computer should be the compass that steers our efforts to exploit technology for educational purposes: while it is the platform for Personalized Instruction, it is also the technology of the 1980s and 1990s. Today's technology is not just personal but mobile, social, and networked; it is flexible and social in nature, and it permeates other aspects of our lives. This range and flexibility may be largely lost in the model of Personalized Instruction, which focuses on the isolated individual's personal path to a fixed end-point.

What Are the Variables in Personalized Instruction Systems?

The systems lumped together under the umbrella term of Personalized Instruction differ widely. In fact, there is so much variability in features and models for implementation that it is impossible to make reasonable claims about the efficacy of Personalized Instruction as a whole. Worse, when decision makers consider adopting a particular system, it is usually hard to tell whether o available evidence applies to the specific system under consideration. To shine the weak light available on this confusing landscape, the following discussion reviews common options for systems and for implementation models, and the next segment will review the little evidence available on the effectiveness of various options.

Student Choice

One way Personalized Instruction is commonly conceptualized is a way to give *students choices*, allowing them to personalize instruction for themselves. For example, computerized instruction can give *control of the pace* of instruction to students, who can spend as much or as little time on a topic as they need to pass an assessment. This removes the lock-step nature of traditional instruction. A closely related conceptualization is Personalized Instruction as fully online instruction, a way to give students *control over when and where* they learn. This has implications for non-traditional students who may need to work during the traditional school day, and to rural students with limited access to diverse curricula. However, Personalized Instruction has also led to new ways of using face-to-face instructional time within brick and mortar schools; in "flipped" classrooms, for example, students watch lectures for homework and engage small group face-to-face tutorials and other instructional activities during in-class time. Personalized instruction can also provide students with *choice about what topics to study, what learning resources to use, or both*. In mathematics, for example, students may wish to start with graphing and study linear equations later. Or, one student studying linear equations may use a simulation, while another student studying the same topic may choose to use a series of practice problems provided by the system. In all of these cases, Personalized Instruction gives students autonomy over their own learning, and allows each student to take a different path to mastery of the prescribed material. Most systems today offer a combination of the different ways to personalize instruction listed above.

Closely related to the students' choices are the choices that teachers are able to make to personalize instruction for a given student. The degree to which teachers are enabled to make choices to personalize instruction and the degree to which this affects outcomes and cost will be addressed below in the section on implementation models.

Adaptive Learning Systems & Intelligent Tutoring Systems

It is worth noting that none of the student autonomy models outlined above involve any intelligence on the part of the system. They rely instead on the students (or the teacher) to make intelligent choices about instruction. In contrast, a second cluster of models for Personalized Instruction chooses to turn some choices or responses over to the system. As is true for the student autonomy model above, there are several ways to personalize instruction—in this case, by using some amount of "artificial intelligence" in the system.

By far the most common way is to embed assessments into the instructional sequence and then use the performance of students on the assessment to direct them to topics or resources. These systems are often called *Adaptive Learning Systems*. For example, a student studying photosynthesis who comes to the end of the unit may be asked to take a quick quiz. Based on what the student gets right and wrong, the quiz may be followed by additional instruction on important background information or a short video that targets a common misconception revealed in the pattern of answers. A more sophisticated model of intelligent Personalized Instruction is *intelligent tutoring systems* (ITS). In an ITS, students are asked to do exercises and problem sets online; the computer uses their answers during problem solving to model how they are thinking about the topic and provides continuous personalized feedback based on its model of the students' understanding. There are at least two important differences that separate these two models. First, adaptive systems use embedded assessments to determine appropriate next steps, based on assumptions about the structure of the domain being taught or on patterns found in analysis of large aggregates of student data. ITS systems, however, use a cognitive analysis of the specific student interacting with the system as a basis for feedback. Second, Adaptive Learning Systems typically make recommendations after instruction is complete, and those recommendations take the form of additional instruction. ITS systems, on the other hand, give contextualized feedback during instruction relevant to what the students are doing at the moment. If a student is struggling with particular steps of problem solving, for example, ITS feedback will target those steps. A more recent popular model for Personalized Instruction with "intelligence" is games. *Educational games* are personalized in the sense that the system keeps data on each player (including, for example, what topics have been mastered and at what level) and this information affects the gameplay. In some ways educational games put a new façade on autonomous models of Personalized Instruction. Students control the pace or difficulty of the game/instruction, the location and time of gaming, and often even which topic (or quest) they will undertake next. What is different about games is that the instruction is often hidden, or absent. Many games hide instruction in tutorials that help the student figure out how to play, or in hints that students receive when they are stuck. While replacing direct instruction with a game that requires knowledge at various level of play may not seem like a large change, it subtly changes the motivational structure of the activity. Students are no longer motivated by mastery of the material; instead, they are motivated by advancing levels or overcoming an obstacle within the game, so that learning and knowing is made to be subservient to successful game play. Research has not yet determined whether this motivational difference is one that affects conceptual understanding, long-term motivation, or student outcomes.

At the far end of the gaming scale, some educational games eschew instruction altogether. Based on adaptions of behaviorist principles, these games use the conditions and reward structures of the game to train student behavior. Successful training replaces direct instruction in knowledge and skills. For example, in a physics game for young children called RoboBall (http://www.digitalsteamworks.com/project_engage.html) developed by the software developer Digital Steamworks and UCLA's Center for Research on Evaluation, Standards and Student Testing, students encounter a ball that will be propelled though the air towards a target and are left to experiment with what works and what doesn't. They can succeed only by manipulating the game in such a way as to predict where the ball will roll or fly, which is in turn governed by a computer simulation of Newtonian mechanics. The assumption is that if students are able to succeed often enough and in enough varied conditions, they will infer the basis of Newtonian motion without explicit instruction. The levels of the game provide a series of tasks that become increasingly complex, while the reward structure of the game is used to keep students engaged.

What Are the Variables in Implementation?

Variation in what specifically is meant by the term "personalized" is further complicated by the ways that schools integrate Personalized Instruction into institutional structures and classroom routines. There are at least two major implementation models: 1) completely online instruction, and 2) "blended" instruction, which combines face-to-face and online instruction. There is strong potential for implementation models to interact with or mediate the effects of any given model of Personalized Instruction.

Online instruction

Some schools have turned to a model of completely online instruction, at least for some classes or content areas. Additionally, there are an increasing number of new schools being opened with no brick-and-mortar campus at all. In the fully online model, the flexibility to study when and where you want expands the opportunities for access to instruction. At the same time, however, the model constrains student-teacher interactions to email and discussion boards, which may limit the richness and effectiveness of the learning experience. As discussed below in the cost analysis section, new all-online schools also raise serious questions about funding for online instruction. In a number of cases, fully online schools have been funded at the same level as traditional schools, despite having different costs associated with the physical plant and human capital.[15]

Blended instruction

Far more common are schools and districts that are experimenting with blended instruction where some, but not all, instruction is delivered online. This model is favored because it allows teachers new-found flexibility in terms of who they give their attention to and what type of interactions they have with their students. Teachers may choose to offload remedial instruction of background knowledge to the online environment. Freed from having to lecture and review earlier material with students who are behind, teachers may spend their time implementing more engaging activities or more challenging work, or perhaps providing individualized feedback to students. Leaving the choice of how to use technology for which students in the hands of local educators has, however, prompted some controversy. Research has found that schools in less affluent areas are more likely to use the technology for remedial instruction and for drill and practice, whereas affluent schools are more likely to use technology in ways that advance problem solving and conceptual understanding.[16] These choices, often left up to individual teachers, have serious implications for equity within the classroom and across schools and districts.

The most common way to blend online and face-to-face instruction is the station rotation model.[3] In this model, students are divided into groups and each group goes to a different station—allowing for one station where the teacher can work with a smaller group of students on a focused activity. Another model for blending online and face-to-face instruction is the “flipped” classroom where topics are introduced online—either through videos or interactive instructional materials—and the teacher uses the face-to-face time for activities, group work or individualized feedback.

These implementation models vary both in their potential to cut costs and in their effects as they co-exist with other types of instruction. For example, it may be that “flipped classrooms” are less effective when instruction is delegated to Intelligent Tutoring Systems or games—models of personalization that often do not provide explicit instruction.

Review of Research

The first question that must be asked of any educational technology is how it affects student learning: if technology is cheaper—but ineffective—it will be no bargain for schools. But then: is it cheaper? This segment reviews what the research suggests about these two key issues: instructional efficacy and cost.

Analysis of the evidence for instructional efficacy

Meta-analyses

Now that digital technologies have matured, what is the evidence that educational technologies improve learning outcomes for K-12 students? Unfortunately, if one looks to large-scale, well-designed, quantitative studies for guidance, there is little reliable evidence on outcomes. A recent U.S. Department of Education report on educational technology was unable to find enough well-designed studies in the K-12 context to perform a meta-analysis on the efficacy of Personalized Instruction.[17] Instead, they had to turn to undergraduate, graduate, and professional training contexts to have enough statistical power for a meta-analysis of Personalized Instruction. Even given large bodies of data, however, the tremendous variability in what is meant by Personalized Instruction (as detailed above) makes it likely that the body of data for any meta-analysis contains not only many apples and oranges, but a fair number of peaches, pears and plums as well. This variability, combined with the dearth of large scale studies on the effectiveness of Personalized Instruction for K-12 schools, creates a complex landscape for policymakers to navigate when dealing with vendors, setting funding priorities, or dealing directly with educational institutions. But, decision makers must move forward—with the best information available.

It is true that the features and structures of Personalized Instructional systems are much the same regardless of student age. Therefore, results of studies from higher education (the best information available) are cited here—along with the critical caveat that student motivation and instructional content at the K-12 and college levels differ in important ways that may well affect student outcomes.

At first glance, the results of the most recent meta-analyses are consistent with the lackluster findings of prior meta-analyses. Moving instruction completely online showed no difference in learning outcomes when compared with face-to-face instruction, although one study showed a slight decline.[18] Blended instruction models showed a modest advantage (a .2 effect size[*]) when compared to face-to-face instruction[19]. Further, while analyses demonstrate that technology is improving, outcomes based on the latest advances in digital technologies are not improving at a rapid pace. Studies conducted from 2004-2009 showed a .008 increase in effect size when compared to studies that used technologies that were state of the art from 1997-2003. It is important to note as well that outcomes primarily reflected procedural (or *how to*) knowledge, not increased efficacy for declarative (*informational*) knowledge or strategic thinking. That is, improvements do not effectively yield the type of conceptual understanding, problem solving and complex thinking that the current economy requires.

---

* An effect size is a measure of how large the difference is between two groups. It is more helpful in this context than are measures of statistical significance, because it is less dependent on sample size. An effect size of 0.2 is roughly equivalent to having a student who was scoring in the 50th percentile in standardized assessments move up to the 58th percentile by virtue of being in the other group—an educationally significant but modest gain.

There is, as noted above, a conflation of models considered these meta-analyses that leaves some question about their reliability. Breaking things down a bit further, however, does not dramatically change the picture. In terms of the efficacy of student autonomy, four studies showed evidence that allowing the student to control the topic and/or the modality of instruction improved outcomes.[20] However, three other studies failed to find any effect for student autonomy.[21] Likewise, a number of studies found that embedded assessments and quizzes that simply inform students and teachers about correct and incorrect responses did not improve outcomes. For assessments to be effective, they needed to be tied to recommendations for specific problem sets, resources, or specific feedback. That is: systems needed to have some amount of intelligence for embedded assessments to be useful.[22]

While there were not enough K-12 studies to run a meta-analysis, there have been several evaluation studies worth mention. None, however, presents compelling evidence in favor of Personalized Instruction. An evaluation study by SRI Education of the Khan Academy[23] examined nine school sites that used the Khan software for one or two years. The sample included public, charter, and independent schools. Five of the nine sites studied used the station rotation implementation of blended instruction while the other four sites used a mix of different implementation models. This was somewhat surprising, since the Khan Academy is most closely tied to the flipped classroom model. While the study did find an association between the time spent on online activities and improvement in student test scores, the method could only indicate if scores were higher or lower than the previous year – not how much the scores improved. Further, in three out of the four schools that used the Khan academy software for two years, the time students used the software went down significantly in the second year.

A different report on blended learning conducted by SRI[24] collected data in five sites that included 12 schools over the course of one year. The study examined three schools in one site for a closer look at how blended learning affected standardized test scores. The study compared these schools, which implemented blended learning in their mathematics classes, with three schools in the same district that used traditional teaching methods. After controlling for prior achievement, the study found no effect of blended learning when compared with face-to-face instruction. In fact, the comparison schools did better than the blended learning schools, even though students in the blended learning schools reported spending more time on instruction out of school. Finally, this study directly tested the argument that blended instruction is particularly helpful for lower-achieving students. The study examined the standardized test scores for the same three blended learning schools compared with three other schools in the district to see if the gap between high and low achievers was closed by using blended instruction for one year. The study showed that neither blended learning nor face-to-face instruction in this district was particularly successful at improving the performance of lower achieving students. The gap closed 3% in the blended learning schools compared with the 2% improvement in the comparison schools that used conventional teaching methods.

The most promising report on a large-scale implementation of Personalized Instruction was recently published by the Bill & Melinda Gates Foundation.[25] The report documents the progress of 23 schools, ranging from kindergarten through high school, that implemented Personalized Instruction systems for the last two years. The systems shared a set of features that included imbedded assessments, learner profiles, and the ability of the student or teacher to choose a path through the material based on the profile. Unfortunately, the report gives little detail on exactly how the system was implemented, only noting that over half the schools made structural changes to staffing, flexible schedules, and/or extending the length of the school day or year. From the survey questions, however, it seems clear that some sort of blended model was adopted, as 40% the teachers reported that students used technology for over 50% of the in-class time. Of particular note was that the teachers reported regularly using the large amounts of data collected on each student to make instructional decisions—a departure from findings of other implementation studies. The achievement outcomes for these 23 schools were stronger than found in other studies, with an average effect size of 0.41 in math and 0.29 in reading when compared to a "virtual control group."

A caution here is the nature of the virtual control group, which was the basis of comparison for the students of these 23 schools. The control group students were from an undisclosed number of schools who took the same assessment. It is unclear how comparable these students' schools were, since they were only matched on three factors: if they had a similar type of location (e.g., urban), if they were schools of choice (e.g., charter schools), and if they had a similar proportion of low income students. This means that nothing is known, much less controlled for, about other differences in the communities or the families or about the comparison group's pedagogies—and as Barbara Means and her colleagues note, pedagogies matter.[26] Further, the SRI study[27] noted above found that when the comparison group is comprised of a number of schools using similar pedagogies, there was no effect for blended instruction.

In sum, except for the recent report by the Bill and Melinda Gates Foundation,[28] meta-analyses and comparisons involving multiple Personalized Instructional models offer little evidence that such technology improves learning outcomes. While technologies are improving at a rapid rate, the improvements are not translating into rapid improvements for student outcomes. Finally, the evidence does not help pinpoint which set of features in these systems is the active ingredient of their limited success. Given that only blended models—models that combined face-to-face instruction with online instruction—showed any improvement, one can question whether the results were influenced primarily by the technology, or by the change in how teacher time was spent with students. In fact, Barbara Means and colleagues[29] noted that most study designs do not control for pedagogy at all. That is, not only is the medium changing from face-to-face to online, but the instructional procedures, assessments, and classroom routines are changed as well. In fact, when controlling for pedagogy—teaching all the students the same way but only varying access to personalized online instruction—blended instruction no longer showed and improvement over face-to-face instruction[30].

Intelligent tutoring systems

The outcomes for intelligent tutoring systems are more promising, but far from compelling. While there have been numerous small-scale laboratory studies showing positive results for various ITS systems over the last 20 years, the meta-analyses and larger scale studies report mixed results. Evaluations of the most widely used ITS system, the Cognitive Tutor for Algebra 1 developed by Carnegie Learning, were examined by RAND.[31] A study of 73 high schools and 74 middle schools over two years yielded contradictory findings. In the first year of the study the use of the ITS had no statistically significant effect, but instead showed a non-significant negative trend for students using the software. In the second year of the study, both the middle and high schools showed a significant positive effect, with an effect size of about .2. While well short of the two-sigma standard set by human tutoring, this is a meaningful improvement: it suggests that a student who was scoring in the 50th percentile in standardized assessments would move up to the 58th percentile with the aid of an ITS.

What is curious, however, was that the improvement from the first year of the study to the second year was not due to a better implementation of the software. Instead, the authors report that the main difference between the two years was that the teachers "reverted somewhat back toward the more traditional practices over time."[32] It is worth noting that in all the cases, as per the recommendation of the developer, the ITS was implemented in a blended classroom model. At most, students were using the ITS system 3 days a week. When the system was implemented as intended by the developer in the first year, there were no positive effectsbut when teachers used the time away from the computer to return to traditional practices, such as lecturing, the study showed a positive effect. This result reinforces the importance of mediating factors such as pedagogy and the implementation model used. Other medium-scale studies of the cognitive tutors show similar mixed effects. In the six studies that met the U.S. Department of Education's "What Works Clearinghouse" standards for rigor, four studies showed no effect, one study showed a positive effect, and one study showed a negative effect.[33]

The trend for the ITS model is to show great promise in small-scale studies, but to return mixed results at scale in K-12 classrooms. This holds true for the various math tutors, for different age groups, and for the limited number of subjects for which ITSs are available (primarily math, reading comprehension, programming, and to a lesser extent science).

Games

In many ways educational games sit somewhere between ITS and un-intelligent, student autonomy models. Games do model individual users based on their current and past performance, but typically do not use complex, cognitive models of users in the way that ITSs do. Like student autonomy models, most educational games are premised on student choice and control. Students choose which "quest" or challenge to take on, and the primary objective of game designers is to capture and keep student interest by allowing these choices. Further, just like ITS and other models of Personalized Instruction, what gets called a game varies greatly, as do student outcomes.

A recent meta-analysis of 77 digital games for K-12 learning published by SRI again produced confusing results.[34] When studies compared game playing to other forms of instruction, games showed a positive effect. However, when game playing was compared to no-treatment control conditions there were "no beneficial effects of digital games on learning outcomes."[35] The authors were quick to point out that a limitation of their findings was that what the developers called a *game* differed so greatly in terms of the features offered and production values that that more analysis was needed to explore the relationship between game design and learning outcomes.

Cost Analyses

Economists define increasing productivity in terms of either efficiency—reducing costs while maintaining quality—or effectiveness—increasing quality without increasing costs.[36] However, when it comes to education, there is evidence that the priority goal is the latter. Rhetoric promoting current educational policy suggests that the United States must increase the current level of achievement to increase its global competiveness, to rebuild its middle class, and/or to address the longstanding disparities in achievement tied to race and social class.

Unfortunately, as University of California President Janet Napolitano recently noted, online education—when done well—does not decrease costs. Studies that looked at the cost of moving all instruction online (which, according to the studies above, will likely lead to no improvement in educational outcomes) found little savings. Again when one looks closely at the data one sees tremendous variability. While some studies based on self-reports have estimated the savings to be up to $3,600 per student per year,[37] others[38] found that when capital and transportation costs are excluded, the cost of a completely online education is the same as a brick-and-mortar school. Florida's pilot tests of completely online schools serves as a good example. Florida funded its virtual schools at levels just $700 per student less than traditional schools about a 10% savings[39]. Because the savings were small when one considers the lack of investment in physical infrastructure, many states reacted by legislating a lower reimbursement rate for virtual schools, leading in turn to complaints from the companies that provide these courses that they are being underfunded. As one can see establishing a fair price for online education promises to be a thorny issue, but vital if the intended cost-savings are to be realized.

Blended models show the most promise, but raise the cost of education. This is because while there are new costs associated with computerized instruction, such as licenses, increased technical infrastructure, maintenance, and professional development—the existing costs of traditional education are reduced but not eliminated. In one RAND study,[40] based on the actual expenditures of schools that transitioned to an Intelligent Tutoring System for Algebra 1, the cost increased an average of $120 per student for the one course. This increase was reduced to $70 per student per class in schools with a good existing technological infrastructure. However, as many as half the schools in implementation studies undertaken by SRI Education[41] and RAND[42] were found to need a substantial investment in their technological infrastructure before they could take advantage of Personalized Instruction.

Additionally, when considering the transition towards personalized computer instruction, important considerations include changes in staffing and the costs of these changes. Licensing and other costs associated with software systems often result in a reduction in the size of the professional teaching staff; such reductions are often accompanied by an increase in the number of paraprofessionals on staff who, in the blended implementation model, provide the majority of direct contact hours with students. It is yet unclear how this combination of a small number of highly skilled teachers combined with a larger number of low-skilled, low-paid paraprofessionals and teaching assistants will affect the costs and learning outcomes of these systems. And, in addition to shifting the make-up of faculty, increased use of personalized system will change the skill set of faculty using blended and other models. Most notably, teachers will need a new set of skills that allow them to access, interpret, and use the large amounts of data on individual students that personalized systems collect. Teachers are not currently required to have such skills, so it is perhaps not surprising that the teacher dashboards are one of the least used features in personalized systems.[43]

Discussion and Analysis

Clearly there is plenty of room to improve public K-12 education in the United States. We are the leader in spending per student and overall, spending over $11,000 for each elementary and secondary student—39% higher than the average of $8,500 for other countries included in the PISA study.[44] We struggle to match the expectations we set for ourselves,[45] however, and are outperformed in international comparisons of math and science outcomes.[46] Worse yet is that the statistics and inferences often drawn from the international and national assessments tend to gloss over the great disparities in funding and social class within our nation.[47] In the U.S. and elsewhere, students at the bottom of the distribution of socio-economic status perform worse than students higher in the distribution. In the U.S. the overall average performance appears to be low in comparison to other countries because we have so many more test takers from the bottom of the social class distribution who are not receiving the same quality of education that others do.

While the issues facing our schools are complex and there is no one solution, or even one problem, part of the solution must be to improve the pedagogy that goes on in many of our classrooms. The factory model of education has been critiqued for over thirty years with good justification.[48] Teachers lecturing to grade-banded students, lock-step assignments, worksheets that promote memorization without understanding, and standardized assessments that focus on a shallow understanding of a large number of topics all go against what research has demonstrated leads to lasting and generative learning.[49]

It is also reasonable to assume that technology will be part of the solution. Clearly, as we move forward, technology will be in the classroom in one form or another. It is unrealistic and irresponsible not to figure out how to use technology well. Any tool has the potential to transform practice, and computers have a particularly good track record in other sectors. Technology has been responsible for transformational change in other areas of our lives, and technology now defines the workplaces for which we strive to prepare our students. Finally, given the U.S.'s already high investment in public education with a large percentage of these funds devoted to the salaries and benefits of teachers and staff, technology looks enticing with its promise of a cost-effective solution.

Personalized Instruction, in all its many forms, does not seem to be the transformational technology that is needed, however. After more than 30 years, Personalized Instruction is still producing incremental change. The outcomes of large-scale studies and meta-analyses, to the extent they tell us anything useful at all, show mixed results ranging from modest impacts to no impact. Additionally, one must remember that the modest impacts we see in these meta-analyses are coming from blended instruction, which raises the cost of education rather than reducing it.

Until we develop a clear vocabulary for educational computing that distinguishes between the features being offered in different systems, studies that evaluate these systems will continue to compare apples to oranges. Another way to encourage apples to apples comparisons would be to require that if and when national standards are in place that the content and features of these systems align with them. There is legitimate debate about the amount of testing associated with these new standards, the developmental appropriateness of them, and even the value of national standards at all. For the purpose of helping to create a context where we can finally reliably assess the effectiveness of Personalized Instruction, however, the current standards focus on "practices" rather than just what content needs to be learned encourages many of the approaches to instruction that current cognitive and Learning Sciences research supports. The combination of a clear vocabulary for the features offered, a shared set of pedagogical goals for instruction, and a common set of topics to be taught would allow us to begin to effectively compare and evaluate these systems. Developing this consensus will require partnerships between developers who make the systems, researchers who evaluate them, and the teachers who use them. Without structures to bring these stakeholders together, it will be difficult to develop any common ground.

To truly harness the power of modern technology, we need a new vision for educational technology. We need technologies that are based on what we know about the process of learning and take advantage of the mobile, networked technologies of today.

One might optimistically pursue Personalized Instruction driven by market forces in spite of the lack of transformational change it has produced to date. After all, given the ambiguity of the results one might choose to believe that when the chaff was separated from the wheat, the outcomes will be stronger. With the recent development of blended instructional models and the research that points to just how much the method of implementation mediates student outcomes, there is some reason to hope that as implementation strategies mature more dramatic improvements in outcomes and cost savings will finally appear. However, for this hope to be realized we would need to invest heavily in the professional development of teachers. Many of the practices they need to engage with to be an effective teacher within the realm of Personalized Instruction are different than current training programs or prior experience has prepared them. At the top of the list is training in making decisions based on the large amounts of data these systems generate about each student. Such strategic data analysis is not something that is currently in the typical teacher's toolbox.

It might, however, be more prudent to look elsewhere for opportunities to improve educational efficacy. As mentioned in the introduction, Personalized Instruction is based on the metaphor of personal desktop computers—the technology of the 80s and 90s. Today's technology is not just personal but mobile, social, and networked. The flexibility and social nature of how technology infuses other aspects of our lives is not captured by the model of Personalized Instruction, which focuses on the isolated individual's personal path to a fixed end-point. To truly harness the power of modern technology, we need a new vision for educational technology. We need technologies that are based on what we know about the *process of learning* and take advantage of the mobile, networked technologies of today. Up to this point I have been careful to use the term Personalized Instruction and not the term personalized learning. The focus of the systems reviewed thus far is exclusively on instruction, and not on the process of learning. Learning has always been an interactive experience—observation of others, questioning and being questioned, dialog, discussion, and debate. These are interactions between people. The relationships between people that are formed during these interactions help students not only to understand new information but to trust it and to value it. The irony here is that an approach that reduces the time students spend interacting with teachers and other students is called "personalized."

The type of computer technology that many believe will lead to transformational change will be technologies built around the process of learning and that attempt to enhance human-to-human interaction, not supplant it: technologies that spark conversations and inquiry; technologies that support these conversations with tools for visualization, simulation, analysis and communication; technologies that allow the students to create physical or computational objects; and technologies that allow students to share their ideas and solutions with their peers and larger social networks for feedback and refinement. There are many promising new models for how computers should be used to support learning. One such model that captures the spirit of much of the list above is called Computer Supported Collaborative Learning.[50]

To be fair, this new metaphor and genre of technology has not yet been proven more effective than Personalized Instruction with the type of large-scale implementations or meta-analyses reviewed above. It is simply too recent a development for large-scale studies. However, technologies that don't teach, but rather provide opportunities for learning, have several potential advantages. They are informed by current theoretical and empirical work in the Learning Sciences.[51] They are a better fit with the current technological landscape outside of schools, which focuses on mobile and socially-networked computing. What is more, they are designed from the get-go around the blended learning implementation model, which seems to be the most promising way to implement technology when it comes to increasing learning outcomes.

Recommendations

If we continue to pursue Personalized Instruction, despite its lackluster outcomes and expense, a number of recommendations seem clear from the findings to date:

- Education policymakers should continue to invest in technology but should be wary of advocacy promoting computerized instruction to an extent that oversteps the current research. Policymakers should pursue an incremental path with technology.
- Policymakers and researchers should clearly distinguish among key systemic features of technologies in use. "Personalized Instruction" is too broad and vague an umbrella term to allow for meaningful evaluation or to guide policy.
- Researchers should design studies focused on the K-12 context, because much available evidence to date has been extrapolated from studies done at the undergraduate and professional levels, where developmental and motivational factors differ.
- Setting aside the controversy surrounding national academic standards, where academic standards are in place educators adopting instruction via technology should insist that developers provide software aligned with the standards. In one implementation study where these standards were adopted,[52] 66% of the teachers reported the lack of the system's alignment with standards as a barrier to effective implementation. Adopters might also consider seeking software that reflects national assessment systems being developed (such as the Smarter Balanced Assessments), so that instructional systems parallel accountability systems and can possibly alleviate some of the onerous and time consuming aspects of testing to the high standards set by the Common Core and Next Generation Science Standards.
- Policymakers should encourage more partnerships among developers, educational researchers and teachers. Such partnerships have great potential to produce systematic and rigorous evidence of what works and what doesn't, including studies that take into account the various combinations of technical features, pedagogical approaches and implementation models. We cannot trust market forces alone to sort out which systems are effective.
- Administrators must ensure that investments in technological infrastructure and software licensing are accompanied by substantive professional development for teachers in order to provide them with skills that have not historically been in the teacher's toolbox. Particularly important will be providing teachers with practice with using technological data on student performance to guide instructional decisions for individual students.
- All stakeholders should refrain from assuming that Personalized Instruction is the only model for computers in the classroom and be open to investigating new models integrating technology into the learning process.

Notes and References

1 Woodworth, K., Greenwald, E., Tyler, N., & Comstock, M. (2013). *Evaluation of the first year of the Oakland Blended Learning Pilot. A report to the Rogers Family Foundation.* Menlo Park, CA: SRI International. Retrieved Nov. 14, 2014, from http://www.sri.com/work/publications/evaluation-first-year-oakland-blended-learning-pilot.

2 Collins, A. & Halverson, R. (2009). *Rethinking Education in the Age of Technology: The Digital Revolution and Schooling in America*. New York: Teachers College Press;

Roschelle, J., Pea, R., Hoadley, C., Gordin, D., & Means, B. (2001). Changing how and what children learn in school with computer-based technologies. *The Future of Children, 10*(2), 76-101. Los Altos, CA: Packard Foundation.

3 Cazden, C. (2001). *Classroom Discourse: The Language of Teaching and Learning.* Portsmouth, NH: Heinemann;

Green, E. (2014). Why do Americans stink at math? *New York Times Magazine*;

Lemke, J. (1990). *Talking Science: Language, Learning, and Values*. Norwood, NJ: Ablex Publishing;

Mehan, H. (1980). The competent student. *Anthropology & Education Quarterly, 11*(3), 131-152.

4 Collins, A. (2006). Cognitive Apprenticeship. In K. Sawyer (ed.) *The Cambridge Handbook of the Learning Sciences*. Cambridge: Cambridge University Press.

Hall, R., & Greeno, J. G. (2008). Conceptual learning. In T. L. Good (Ed.), *21st Century Education: A Reference Handbook, Volume One* (212-223). New York: Sage;

Lampert, M. (2001) *Teaching Problems and the Problems in Teaching*. New Haven, CT: Yale;

National Research Council (2000). *How People Learn: Brain, Mind, Experience and School*. Expanded edition. Washington, DC: The National Academies Press.

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

Cuban, L. (1990). Reforming Again, Again, and Again. *Educational Researcher, 19*(1), 3-13.

6 Department of Education (2013). *Budget summary*. Washington, DC: Author.

7 United States. Department of Education. (2010). *A blueprint for reform: The reauthorization of the Elementary and Secondary Education Act*. Washington, DC: Office of Planning, Evaluation and Policy Development, U.S. Department of Education.

8 *Education Week* (2014). Personalized learning: A working definition. Author. Retrieved Nov. Nov. 14, 2014, from http://www.edweek.org/ew/collections/personalized-learning-special-report-2014/a-working-definition.html?cmp=ENL-EU-NEWS1.

9 Patric, S., Kennedy, K., & Powell, A. (2013). M*ean what you say: Defining and integrating personalized, blended and competency education*. iNACOL. Retrieved Nov. 14, 2014, from http://www.inacol.org/cms/wp-content/uploads/2013/10/iNACOL-Mean-What-You-Say-October-2013.pdf.

10 Peligrino, J. (2014). Beyond rhetoric: Considerations of deeper learning and 21st century skills. In J. Bellanca (Ed.), *21st Century Skills: The Deeper Learning Connection*. New York: Solution Tree Press;

Barron, B., Pearson, P. D., Schoenfeld, A. H., Stage, E. K., Zimmerman, T. D., Cervetti, G. N., & Tilson, J. L. (2008). *Powerful learning: What we know about teaching for understanding* (193-211). San Francisco: Jossey-Bass.

11 Britzman, D. P. (1986). Cultural myths in the making of a teacher: Biography and social structure in teacher education. *Harvard Educational Review*, *56*(4), 442-457.

Darling-Hammond, L. (2006). Constructing 21st-century teacher education. *Journal of Teacher Education*, *57*(3), 300-314;

Johnson, A. P. (2006). No child left behind: Factory models and business paradigms. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, *80*(1), 34-36.

12 Drucker, P.F. (1973). Science and industry, challenges of antagonistic interdependence . *Science, 204* , 808-815

13 Reich, R. (1992) *The Work of Nations: Preparing Ourselves for 21st Century Capitalism*. New York: Alfred A. Knopf.

14 Giroux, H. McLaren, P. (1986). Teacher education and the politics of engagement: The case for democratic schooling. *Harvard Educational Review, 56*, 213-239.

15 Glass, G. (2009). *The Realities of K-12 Virtual Education.* Boulder and Tempe: Education and the Public Interest Center & Education Policy Research Unit. Retrieved Nov. 14, 2014, from http://nepc.colorado.edu/publication/realities-K-12-virtual-education.

16 Wenglinsky, H. (1998). *Does it compute? The relationship between educational technology and student achievement in mathematics*. Princeton, NJ: Educational Testing Service Policy Information Center.

17 Means, B., Toyama, Y., Murphy, R., Bakia, M., & Jones, K. (2010). Evaluation of evidence-based practices in online learning: A meta-analysis and review of online learning studies. *Structure*. Washington, DC: U.S. Department of Education;

Means, B., Toyama, Y., Murphy, R. & Baki, M. (2013). The effectiveness of online and blended learning: A meta-analysis of the empirical literature. *Teachers College Record, 115* (3), 1-47.

18 Keefe, T. J. (2003). Using technology to enhance a course: The importance of interaction. *EDUCAUSE Quarterly, 1*, 24-34.

19 Means, B., Toyama, Y., Murphy, R. & Baki, M. (2013). The effectiveness of online and blended learning: A meta-analysis of the empirical literature. *Teachers College Record, 115* (3), 1-47.

20 Cavus, N., H. Uzonboylu, & D. Ibrahim. (2007). Assessing the success rate of students using a learning management system together with a collaborative tool in Web-based teaching of programming languages. *Journal of Educational Computing Research, 36* (3), 301-21;

Dinov, I. D., J. Sanchez, & N. Christou. (2008). Pedagogical utilization and assessment of the statistic online computational resource in introductory probability and statistics courses. *Computers & Education, 50* (1), 284-300;

Gao, T., & J. D. Lehman. (2003). The effects of different levels of interaction on the achievement and motivational perceptions of college students in a Web-based learning environment. *Journal of Interactive Learning Research, 14* (4), 367-86;

Zhang, D. (2005). Interactive multimedia-based e-learning: A study of effectiveness. *American Journal of Distance Education, 19* (3), 149-62.

21 Cook, D. A., M. H. Gelula, D. M. Dupras, & A. Schwartz. (2007). Instructional methods and cognitive and learning styles in Web-based learning: Report of two randomised trials. *Medical Education* 41 (9), 897-905;

Evans, K. L. (2007). Learning stoichiometry: A comparison of text and multimedia instructional formats. (PhD dissertation). Pittsburgh, PA: University of Pittsburgh;

Smith, C. M. (2006). Comparison of Web-based instructional design strategies in a pain management program for nursing professional development (PhD dissertation). Buffalo, NY: State University of New York at Buffalo.

22 Lewis, B. A. (2002). The effectiveness of discussion forums in online learning. *Brazilian Review of Open and Distance Learning, 1* (1);

Maag, M. (2004). The effectiveness of an interactive multimedia learning tool on nursing students' math knowledge and self-efficacy. *Computers, Informatics, Nursing, 22* (1), 26-33;

Stanley, O. L. (2006). A comparison of learning outcomes by 'in-course' evaluation techniques for an online course in a controlled environment. *The Journal of Educators Online, 3* (2), 1-16.

23 Murphy, R., Gallagher, L., Krumm, A., Mislevy, J., & Hafter, A. (2014). *Research on the Use of Khan Academy in Schools*. Menlo Park, CA: SRI Education.

24 Murphy, R., Snow, E., Mislevy, J., Gallagher, L., Krumm, A., Wei, X., (2014). *Blended Learning Report*. Menlo Park, CA: SRI Education. Retrieved Nov. 14, 2014, from http://www.sri.com/work/publications/blended-learning-report.

25 Bill & Melinda Gates Foundation (2014). *Early Progress: Interim research on Personalized Learning*. Retrieved Nov. 14, 2014, from http://collegeready.gatesfoundation.org/sites/default/files/Early%20Progress%20Interim%20Report%20on%20Personalized%20Learning%20-%20Full%20Report.pdf.

26 Means, B., Toyama, Y., Murphy, R. & Baki, M. (2013). The effectiveness of online and blended learning: A meta-analysis of the empirical literature. *Teachers College Record, 115*(3), 1-47.

27 Murphy, R., Snow, E., Mislevy, J., Gallagher, L., Krumm, A., Wei, X., (2014). *Blended Learning Report*. Menlo Park, CA: SRI Education. Retrieved Nov. 14, 2014, from http://www.sri.com/work/publications/blended-learning-report.

28 Bill & Melinda Gates Foundation (2014). *Early Progress: Interim research on Personalized Learning*. Retrieved Nov. 14, 2014, from http://collegeready.gatesfoundation.org/sites/default/files/Early%20Progress%20Interim%20Report%20on%20Personalized%20Learning%20-%20Full%20Report.pdf.

29 Means, B., Toyama, Y., Murphy, R. & Baki, M. (2013). The effectiveness of online and blended learning: A meta-analysis of the empirical literature. *Teachers College Record, 115*(3), 1-47.

30 Means, B., Toyama, Y., Murphy, R. & Baki, M. (2013). The effectiveness of online and blended learning: A meta-analysis of the empirical literature. *Teachers College Record, 115*(3), 1-47.

31 Pane, J. McCaffrey, B, & Karam, R. (2014) Effectiveness of cognitive tutor algebra i at scale. *Evaluation and Policy Analysis, 36* (2), 141. DOI: 10.3102/0162373713507480.

32 Pane, J. McCaffrey, B, & Karam, R. (2014) Effectiveness of cognitive tutor algebra i at scale. *Evaluation and Policy Analysis, 36* (2), 141. DOI: 10.3102/0162373713507480.

33 IES (2013). *Performance of U.S. 15-year-old students in mathematics, science, and reading literacy in an international context: First look at PISA 2012*. Washington, DC: National Center for Educational Statistics, Institute of Education Sciences, U.S. Department of Education.

34 Clark, D., Tanner-Smith, E., Killingsworth, S ., & Bellamy, S. (2013). *Digital Games for Learning: A Systematic Review and Meta-Analysis* (Executive Summary). Menlo Park, CA: SRI International. Retrieved Nov. 14, 2014, from http://www.sri.com/sites/default/files/brochures/digital-games-for-learning-exec-summ_0.pdf .

35 Clark, D., Tanner-Smith, E., Killingsworth, S ., & Bellamy, S. (2013). *Digital Games for Learning: A Systematic Review and Meta-Analysis* (Executive Summary). Menlo Park, CA: SRI International. Retrieved Nov. 14, 2014, from http://www.sri.com/sites/default/files/brochures/digital-games-for-learning-exec-summ_0.pdf.

36 Levin, H.M. &McEwan, P.J. (2001). *Cost-Effectiveness Analysis: Methods and Applications*, 2nd ed. Thousand Oaks, CA: Sage.

37 Battaglino, T., Haldeman, M., &Laurans, E. (2012). *The Costs of Online Learning*. Washington, DC: Thomas B. Fordham Institute.

38 Anderson, A.J., Augenblick, D., DeCesare, D. & Conrad, J. (2006). *Costs and Funding of Virtual Schools: An examination of the cost to start operate and grow virtual schools and a discussion of funding options for states interested in supporting virtual school programs.* Report prepared for the BellSouth Foundation. Denver, CO: Augenblick, Palaich, and Associates.

39 Glass, G. (2009). *The Realities of K-12 Virtual Education*. Boulder and Tempe: Education and the Public Interest Center & Education Policy Research Unit. Retrieved Nov. 14, 2014, from http://nepc.colorado.edu/publication/realities-K-12-virtual-education.

40 Daugherty, L., Phillips, A., Pane, J. F., & Karam, R. (2012). *Analysis of Costs in an Algebra I Curriculum Effectiveness Study*. Santa Monica: RAND Corporation.

41 Woodworth, K., Greenwald, E., Tyler, N., & Comstock, M. (2013). *Evaluation of the first year of the Oakland Blended Learning Pilot*. *A report to the Rogers Family Foundation*. Menlo Park, CA: SRI International. Retrieved Nov. 14, 2014, from http://www.sri.com/work/publications/evaluation-first-year-oakland-blended-learning-pilot.

42 Daugherty, L., Phillips, A., Pane, J. F., & Karam, R. (2012). *Analysis of Costs in an Algebra I Curriculum Effectiveness Study*. Santa Monica: RAND Corporation.

43 Woodworth, K., Greenwald, E., Tyler, N., & Comstock, M. (2013). *Evaluation of the first year of the Oakland Blended Learning Pilot. A report to the Rogers Family Foundation.* Menlo Park, CA: SRI International. Retrieved Nov. 14, 2014, from http://www.sri.com/work/publications/evaluation-first-year-oakland-blended-learning-pilot.

44 Organization for Economic Cooperation and Development (OECD). (2013*). PISA 2012 Assessment Framework—Key Competencies in Reading, Mathematics and Science*. Paris: Author.

45 National Center for Education Statistics (2011). *The Nation's Report Card: Mathematics 2011* (NCES 2012-458). Washington, DC: Institute of Education Sciences, U.S. Department of Education.

46 Organization for Economic Cooperation and Development (OECD). (2013). *PISA 2012 Assessment Framework—Key Competencies in Reading, Mathematics and Science*. Paris: Author.

47 Carnoy, M. & Rothstein, R. (2013). *What do international tests really show about U.S. student performance*. Washington, DC: Economic Policy Institute. Retrieved Nov. 14, 2014, from http://www.epi.org/publication/us-student-performance-testing.

48 Freire, P. (1974). *Pedagogy of the oppressed*. New York: Seabury Press;

Toffler A. (1980). *The Third Wave*. Bantam Books USA.

49 National Research Council (2000). *How People Learn: Brain, Mind, Experience and School*. Expanded edition. Washington, DC: The National Academies Press.

50 Stahl, G., & Hesse, F. (2007). Welcome to the future: IJCSCL volume 2. *International Journal of Computer-Supported Collaborative Learning, 2*(1), 1-5.

51 National Research Council (2000). *How People Learn: Brain, Mind, Experience and School*. Expanded edition. Washington, DC: The National Academies Press.

52 W Woodworth, K., Greenwald, E., Tyler, N., & Comstock, M. (2013). *Evaluation of the first year of the Oakland Blended Learning Pilot*. *A report to the Rogers Family Foundation*. Menlo Park, CA: SRI International. Retrieved Nov. 14, 2014, from http://www.sri.com/work/publications/evaluation-first-year-oakland-blended-learning-pilot.