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Technology and Education: A primer

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Executive summary

The advance of technology touches our daily lives in ways both subtle and prominent. Over the last 100 years, the introduction of new technologies and innovation in existing technologies have fundamentally changed and reordered almost every aspect of life. Think, for instance, of how we communicate, travel, work, and even relax, and you are hard pressed to find an activity that has not been materially altered by technology.

Yet there is one aspect of life where very little has changed over the last century: education. It is the one area where a professional from 1913, in this case a teacher, could very well be transported to 2013 and adapt quite easily to the working environment of the modern day. For all intents and purposes, we educate our children in much the same way as we did a century ago.

Despite this stubborn attachment to an instructional model from a bygone era, technology is set to revolutionize the learning process. Examples range from simple alternatives like whiteboards that replace older technologies (chalkboards) to interactive lessons that adapt to a specific student's learning style—while providing teachers with real-time feedback on student comprehension of subject matter—to lectures taught by a single professor to tens of thousands of students around the world who are enrolled in Massive Open Online Courses (MOOCs). Such innovations have the potential to radically alter the nature of learning.

Adaptive technology is defined as software that learns and alters itself based on the user's inputs, while allowing for interaction with a broad base of learning styles. It is based on the theoretical concept of adaptive learning as regularly applied in coaching or tutoring. When an issue is identified with the subject, the coach/tutor is able to offer guidance in an individualized manner in order to maximize the pupil's learning potential. Adaptive technology software fills the role of the coach/tutor.

Should this technology be adopted in classrooms, it holds the potential for changing a teacher from a "one-size-fits-all" instructor of material to an individual learning coach. Using the adaptive technology, students can learn the material through an avenue of their choosing and at the pace that best suits them; when they encounter difficulty the teacher can step in and coach them past the problem individually or in a small group, while their classmates continue. In many cases the software is becoming advanced enough to recognize when the student is struggling, and is capable of pre-empting the need for intervention by the teacher.

The emergence of this new and potentially revolutionary technology has not gone unnoticed, but due to the newness of the area there is little existing literature available for reference. The broader education literature does engage with technology in general, but it has struggled to keep pace with the speed of technological innovation, while the dearth of large-scale, longitudinal, empirically-driven research in this field makes the validity of the available results questionable.

The potential revolution in education holds numerous avenues for research by the Fraser Institute and the Barbara Mitchell Centre for Improvement in Education. There are two key areas requiring additional research with respect to adaptive learning in Canada. First, better quantitative, empirical research needs to be completed regarding the actual benefits of adaptive technology and the keys to success with respect to implementing and using it.

The second area, and the one most related to the work of the Fraser Institute, pertains to policy barriers for the introduction of technology. For example, one of the most relevant and immediate questions from a policy perspective relates to quantifying the barriers preventing schools, educators, and education entrepreneurs from introducing and implementing adaptive technology on a broader scale. Other questions, such as the cost of potential technologies given current budget constraints, teacher training, and quality control, are also relevant.

Other potential avenues of research on the impact of adaptive technology relate to homeschooling and education in remote and rural communities, where educational options are limited. The ability to bring into a single enhanced classroom those who suffer from substandard educational options (e.g., schools in the Far North or on aboriginal reserves), or who currently learn outside of the traditional education system, is an obvious area for additional research.

There are a host of other technology-related issues that require additional analysis, such as the impact of MOOCs on post-secondary education.

The struggle to change the way we educate our children is a question, not just of developing a better mousetrap, but of opening up the marketplace to those mousetraps. As Sal Khan, creator of the world famous Khan Academy, observes, “the conventional educational establishment seems oddly blind (or tragically resistant) to readily available technology-based solutions for making education not only better but more affordable, [and] accessible to far more people in far more places” (Khan, 2012: 181). Policy and technology must work together so that all children can benefit.

Introduction

The advance of technology touches our daily lives in ways both subtle and prominent. Over the last 100 years, the introduction of new technologies and innovation in existing technologies have fundamentally changed and reordered almost every aspect of life. Think, for instance, of how we communicate, travel, work, and even relax, and you are hard pressed to find an activity that has not been materially altered by technology.

Yet there is one prominent part of our lives that has changed very little over the last century: education. It is the one area where a professional from 1913, in this case a teacher, could very well be transported to 2013 and adapt quite easily to the working environment of the modern day. For all intents and purposes, we educate our children in much the same way as we did a century ago.

This is not to argue that technology has not had an impact on the classroom. The arrival of the computer and ushering in of the information age have affected traditional education in marginal ways and created the potential for wholesale changes in how students interact with their teachers, learning materials, and peers. However, the fundamental structure of a teacher standing at the front of a class, instructing a room full of students in a "one-size-fits-all" manner, remains similar to what it was 100 years ago.

The Fraser Institute, specifically the Barbara Mitchell Centre for Improvement in Education, have initiated a series of studies examining the role and nature of educational technology, its potential to revolutionize education and solve problems observed in Canada's education system, and the barriers to such improvements.

Educational technologies range from relatively simple replacements for older technologies (e.g., whiteboards for chalkboards) to interactive lessons that adapt to a specific student's learning style—while providing teachers with real time feedback on student comprehension of subject matter—to lectures taught by a single professor to tens of thousands of students around the world who are enrolled in Massive Open Online Courses (MOOCs).

This first paper in the series provides basic background information on education technology with a particular focus on adaptive learning. The key aim of the paper is to provide a broad overview of the technologies available in education, with an emphasis on adaptive learning, as well as of the key policy issues that might affect their introduction and productive use in the future. In many ways, this first paper is meant to provide a foundation and roadmap for future work on education and technology.

The paper begins by evaluating the current landscape of educational technology and providing some key terms, before narrowing the focus to the topic of adaptive learning technology. Following this, the paper takes a detailed look at how some select and cutting-edge schools and other educational initiatives use and implement adaptive learning. Finally, the paper takes a wider view of the interaction of technology and public policy, and the potential for the latter to help or hurt this potential learning revolution.

The current landscape of educational technology

It would be an exaggeration to argue that technology has not influenced classroom teaching. At the same time, however, it is fairly clear that the basic model of educational instruction that existed a century ago is largely still in place. Understanding the different types of technology and their respective applications in education is an important step in comprehending the scale and scope of change that is possible in education through technology.

A host of technologies currently being used in classrooms—computers, projectors, video equipment, and so on—enables teachers to continue to instruct students using the traditional "one-size-fits-all" method dating back as far as the Prussian Empire, but with a modern and, one hopes, more efficient approach.

There are also intermediate technologies that are starting to change the method by which teachers instruct students. Such technologies include game-based interactions, internet-based activities, and limited interactive video and computer programs supported through hypermedia.[1] People interact with hypermedia every day without realizing it, whether clicking on an image on a webpage that leads to a description, watching a video on YouTube, or selecting an MP3 to listen to. This hypermedia software is a fundamental building block of interactive computer programs as it allows a user to branch out from a point of origin, enabling them to select their own path through the information (Woolf, 2009: 351).

Hypermedia is particularly important for this study since it is the basis for many of the emerging technologies that offer the potential to fundamentally alter education instruction. One of those technologies is adaptive learning software, which is the main focus of this paper.[2]

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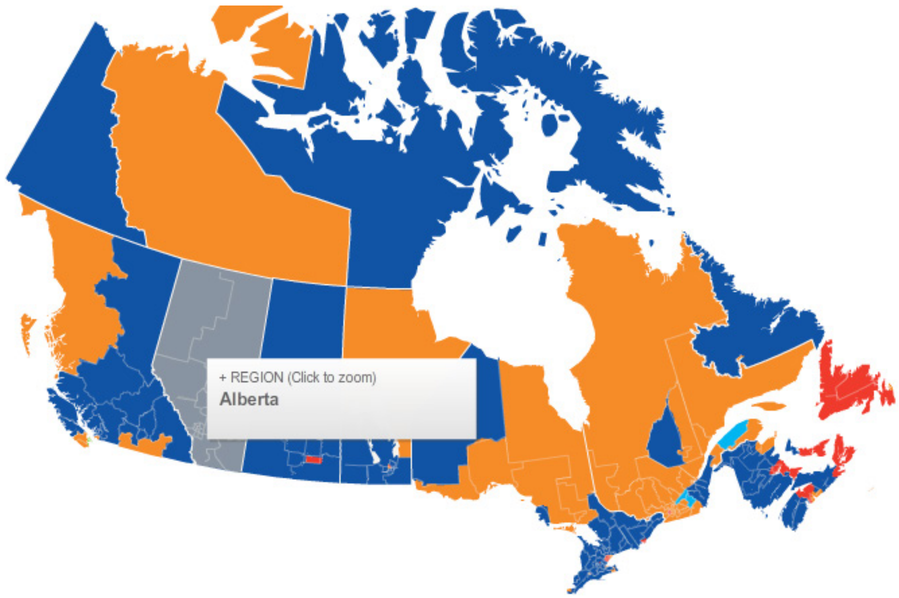
1. Hypermedia refers to non-textual information, such as images, movies, and sounds, that connect to other information in a software program. See Schoonmaker, 2007.

2. Adaptive technology is not solely applicable to educational technology, as the same principles have been applied to technological products in business (particularly in marketing and analytics), health care for diagnostic training, and a variety of other high-technology fields such as artificial intelligence and cognitive computing.

Hypermedia is a fundamental building block of interactive applications. This example, a screenshot from the CBC website, shows a map enabling exploration of election results.
Image from http://www.cbc.ca/news/politics/canadavotes2011/map/fullscreen.html



Defining adaptive learning technology

Before delving into how adaptive technology developed and emerged as a potentially revolutionary concept for education, it's worth understanding it as a basic concept. Susan Smith Nash's 2010 book *E-Learners Survival Guide* offers a succinct and accurate description of what is meant by adaptive learning: "If you've ever had private instruction, a tutor or a coach, you've been involved in adaptive learning." As she explains, "[w]hen you hit the ball late, or are using the wrong grip, your coach notices the problem, lets you know what you're doing wrong, shows you how to correct it, and then, works with you until you have it right" (Nash, 2013). The feedback is instant, relevant, detailed, and, most important, is adapted to the individual needs of the student.

In general, Nash observes:

> Adaptive learning hinges on the idea that the course content should adapt to each user in order to achieve a desired outcome (often mastery). It is a way to transform a student's learning into a unique, individualized experience for each learner and by accommodating the diverse needs of individual students, it combats the tendency for "one size fits all" solutions to be boring, unengaging, and ineffectual. (Nash, 2013)

While individual tutoring or coaching can be said to be adaptive, such learning alternatives are not always feasible. Not only can these alternatives be expensive, but coaches and tutors are only available to a few students and only for a limited number of hours per day or week. This is where technology, according to Nash, is critical:

> Often considered "smart" programs, the online or computer-based education programs adapt or modify the sequence and content of the lessons and courses based on the learner's responses to assessment (formative and summative) questions that can take place during the lesson. It is useful because the experience replicates having a live tutor or mentor who can diagnose and guide students. (Nash, 2013)

Referring to its own LearnSmart software, the McGraw-Hill company summarizes the advantages of adaptive learning:

> Adaptive learning is a method of education that seeks to personalize learning by using sophisticated algorithmic technology to continually assess students' knowledge, skill, and confidence levels, and design targeted study paths based on the resulting data to bolster students' understanding in the areas where they need to improve the most. By allowing students to focus their out-of-class study time on the topics and concepts that are most challenging to them, adaptive learning has been shown to help students study more efficiently, develop greater proficiency, and earn better grades. Adaptive learning also benefits instructors. By better preparing students for class, adaptive learning enables instructors to spend more time delving into advanced concepts, and engaging students in high-level discussion. (McGraw-Hill, 2013)

"If the software detects that a student is mastering a concept, it will move through the material quickly; if it detects difficulty, it will offer more help."

Surveying various adaptive learning software programs, *The Chronicle of Higher Education* found that adaptive learning programs usually present topics as a series of skills and building-block concepts, and incorporate animation, videos, interactive diagrams, and other web-based features. "Interactive tutors," says the publication, "lead students through mastery of each skill, giving short quizzes, scoring them, and offering additional help, such as extra quizzes and more explanations, when requested" (Fischman, 2011).

Specifically, *The Chronicle* notes that programs, such as the popular Knewton software, track students on "how long they take on each problem, whether they ask for extra help and what kind, whether they go back and repeat a lesson or rush through it, and what types of questions they answer correctly and incorrectly – all matched against data from other students." Programs, like those from industry giant Pearson Education, literally adapt to the user: "If the software detects that a student is mastering a concept, it will move through the material quickly; if it detects difficulty, it will offer more help" (Fischman, 2011).

Emergence of adaptive technology

The origins of this new adaptive learning technology can be traced back to the necessity of assisting students with special needs.[3] Primitive adaptive technologies such as large font type, audiobooks, and closed caption television have long been available for special needs students, but it wasn't until the 1980s that computer technology was identified as a means through which these students could receive the instruction and assistance they required in order to succeed in a classroom setting. These efforts were expanded in the 1990s when the emergence of interactive hypermedia, greater computer availability and the dawning of the internet age allowed for the creation of more effective adaptive and assistive technologies to aid those in need (Bender, 2001: 332-36).

Despite there being a plethora of research on special needs education, only a small fraction of this research focuses on technology with an even smaller portion keeping pace with the developments from technological innovation. An excellent, if dated review of the literature on the subject of the use of technology and students with special needs is Maccini, Gagnon and Hughes (2002). The authors conducted a comprehensive review of the available research that met four criteria: 1) studies targeted students in grades 6–12 with learning disabilities; 2) studies involved instruction or evaluation of performance on general education tasks; 3) studies have been published in refereed journals and measured student academic performance; and 4) studies included technology-based assessment as the independent variable (Maccini, Gagnon, and Hughes, 2002: 248). Their review found a general consensus with respect to recommendations regarding how to improve the delivery of education to special needs students. These recommendations included: 1) implement greater use of hypermedia and hypertext programs, as they show greater learning opportunities than traditional software or teaching methods; 2) continue to incorporate effective instructional practices to support technological teaching methods; 3) program systemic training for students in the use of technology; 4) promote videodisc-based instruction embedded in real-world problem-solving situations to promote generalization; and 5) incorporate effective instructional designs that provide a wide range of examples within the specific software to enhance concept development. Based on these recommendations, the authors infer the need for broader implementation of adaptive technology in special needs classrooms, as their proposed

3. In some of the special needs literature the terms "assistive technology" and "adaptive technology" are used interchangeably. In older literature the "adaptive" term in this context refers to the physical adaption of the hardware or software to the needs of the student based on their physical or mental disability. More recent special education literature has used the term adaptive technology in the same manner as broader educational research.

[T]he use of this technology as a part of interactive and adaptive education in the classroom resulted in greater long-term retention of knowledge when compared with traditional methods of instruction …

changes highlight many aspects of this new technological paradigm (Maccini, Gagnon, and Hughes, 2002: 260).

More recently, a research project on hypermedia and students with Attention Deficit Hyperactivity Disorder (ADHD) found that the use of this technology as a part of interactive and adaptive education in the classroom resulted in greater long-term retention of knowledge when compared with traditional methods of instruction in general. In addition to these findings, their control groups (students without ADHD) were also found to have greater knowledge retention and higher testing scores when compared with those taught by traditional methods (Fabio and Antonietti, 2012: 2035-37). This was consistent with more general research on hypermedia and knowledge retention carried out by Yildirim, Ozden, Yasar, and Aksu, who found similar results when conducting tests on high school biology students without learning disabilities (2001: 213-14).

Together, these results were consistent with the general theoretical literature concerning hypermedia-based learning, which describes the process as building and connecting structures of information through assimilation of environmental stimuli. Effective learning requires the connection between existing nodes of knowledge and the newly created knowledge nodes. Since hypermedia-based technology allows for a number of different means of learning, it allows for stronger connections to be formed, and the stronger these connections the greater the retention of knowledge (Jonassen, 1991: 83-92).

As costs for new technologies have declined and their capabilities have grown, the ability of schools to implement technological programs has similarly expanded (Lewis, 1998: 16–17). Although the technology that was used in the aforementioned projects was not adaptive in nature, broader educational technology has reached a point where the advantages of this basic interactive technology can be enhanced by adaptive elements at a low enough cost to move it beyond special needs classrooms, to augment the learning process for all students.

Although informative in terms of how adaptive technology in education has evolved and developed, the review of research undertaken for this paper indicates a vast gap in sound, empirical research to determine and quantify the potential benefits from the adoption of such technology in education. Some portion of this gap is due simply to the relative newness of adaptive technology, with much of the existing research focusing on the technical aspects of this emerging software.[4]

4. Peter Brusilovsky is a leader in the technical aspects of adaptive technology and e-learning. He has a large library of research found here: http://www.sis.pitt.edu/~peterb/papers.html. Other works include: Jones and Jo, 2004; Karampiperis and Sampson, 2005: 128-147; Durlach and Lesgold, 2012.

Beyond this technical literature, the vast majority of academic research on the subject of technology in the classroom is based on surveys and observational methods of classroom behavior with some form of pre/post-test analysis. The sample sizes tend to be limited, with the research being constrained to a single geographic area: sometimes a specific school district or even a classroom. Although regional/national rankings on educational standards are kept by many government and non-government sources, the ability of those projects to drill down to examine the specific impact of technology advancement on students is limited.

More empirical, longitudinal research is required to better understand the potential for this technology to improve education …

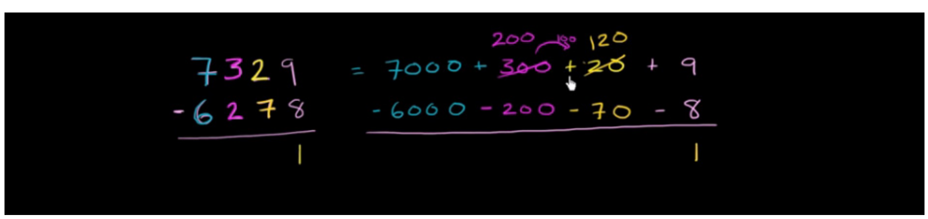
In general, two insights emerge from the examination of how adaptive technology has developed and the existing research. First, the newness of this technology in relative terms has severely limited the research. More empirical, longitudinal research is required to better understand the potential for this technology to improve education and how best to implement and use it. And second, education is clearly entering a period where large-scale disruption of the status quo through new technologies could be the norm rather than the exception.

Case studies in the use of adaptive technology

To better understand the scope for technology to fundamentally alter the status quo in education, the study has summarized a number of existing experiments that rely on adaptive technology to varying degrees.

The Khan Academy – from non-interactive to interactive to adaptive technology

One of the most well-known examples of the effective use of educational technology is the Khan Academy, based in California. What began with a former hedge fund analyst recording short instructional how-to videos on math and science topics for his young relatives has evolved into one of the most well-known and widely used examples of the revolutionary use of educational technology. When people think of computer-based educational technology, they often think of recorded lectures like the Khan videos. As successful as Khan's videos have been (3,400 videos and 200 million views on Youtube), the videos themselves are not interactive or adaptive. Those watching the videos approach this media with different backgrounds and skill levels. There is no interaction between the user and the software beyond the ability to replay the video. Khan himself recognized the limitations of the videos: "Admittedly, just having students watch the videos is not ideal; with DVDs alone, they would not be able to do the self-paced exercises or have access to a great deal of feedback" (Khan, 2012: 224).



In its early iterations, Khan Academy offered video tutorials with no opportunity for interaction.

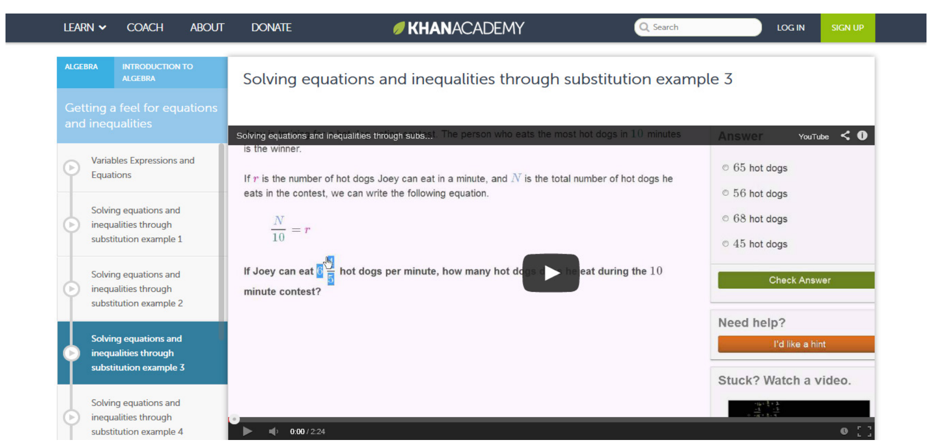
Image from http://www.khanacademy.org

In response to this predicament, Khan wrote some simple software that generated math problems, which students could work on until they understood a concept, and "[i]f they didn't know how to do a particular problem, the software would show steps for coming to the right answers" (Khan, 2012: 135). So the software, even at this primitive level, would adapt to the level of understanding of the student. Khan then refined his software so that the system itself could advise students as to what to work on next.

How this software interacts with students and adapts to their level of understanding is only one part of the story. The software also tracks, compiles and feeds data to teachers so they can better understand how their students are doing, where they are having problems, and when they need to intervene. Khan added a database "that allowed [him] to track how many problems each student got right or wrong, how much time they spent, even the time of day when they were working." Through this database, he discovered that "by expanding and refining the feedback [he] could begin to understand not only what [his] students were learning but how they were learning" (Khan, 2012: 135).

This necessary evolution by Khan and his software shows the potential power of adaptive technology when applied to an educational setting. This process of change is far from over and the potential gains of this new technology for students and instructors—in the classroom and beyond—are yet to be fully realized.

Interactive and adaptive technology are not only altering traditional classrooms but also alternative educational environments like distance education. As technological advances made distance education more practical to provide and easier to take part in, enrollment rates increased but so did dropout rates. The primary problem identified by Stewart et al. (2005) was that distance education is largely conducted without a teacher to provide feedback and support to the student. In these distance education classes, the traditional



The Khan Academy combines instructional videos with practice questions and feedback.
Image from http://www.khanacademy.org

"one-size-fits-all" teaching method is employed; however, this method does not coincide with the various learning styles of those enrolled, and so is not adaptive to the specific needs of the students, which leads to frustration and in turn higher dropout rates (Stewart, Cristea, Brailsford, and Ashman, 2005).

The software overcomes this obstacle by altering the learning environment to suit the needs of the student. Should this technology allow teachers to provide feedback to the individual student it will strengthen distance education as a viable alternative to traditional means of learning (Kosba, Dimitrova, and Boyle, 2007: 379–413). Although distance education is predominantly an avenue traveled by adult or post-secondary students, these advancements do hold promise for lower levels of education, particularly for those students in homeschooling or in rural communities. If adaptive courseware can be employed in distance education it could become a powerful tool to target a large numbers of students in a highly effective manner, particularly if paired with parallel innovations like MOOCs.

The development and use of interactive and adaptive educational software is a relatively recent phenomenon. For instance, Khan did not officially start his online Academy program until 2009. Since then, certain important characteristics have been shared by the increasing number of programs and systems in this field.

LearnSmart

In February 2013, McGraw-Hill announced that it was launching a group of adaptive learning products for Canada, including the first-ever adaptive e-book. The products are part of the company's LearnSmart line of adaptive learning tools. According to the company:

> LearnSmart is an interactive study tool that adaptively assesses students' skill and knowledge levels to track which topics students have mastered and which require further instruction and practice. Based upon student progress, it then adjusts the learning content based on their knowledge, strengths and weaknesses, as well as their confidence level around that knowledge.
>
> LearnSmart's adaptive technology also understands and accounts for memory degradation. It identifies the concepts that students are most likely to forget over the course of the semester—by considering those that they have been weakest on or least confident with—and encourages periodic review by the student to ensure that concepts are truly learned and retained. In this way, it goes beyond systems that simply help students study for a test or exam, and helps students with true concept retention and learning. (McGraw-Hill, no date)

The SmartBook, from McGraw-Hill, is an early example of an adaptive e-book. Image from http://www.mhelearnsmart.ca/

Among the new products in the LearnSmart line is the SmartBook, which is an adaptive e-book that assesses students' knowledge as they read. The e-book asks students questions as they read and, depending on their answers, focuses content to improve learning and comprehension of topics. Thus, instead of the student having to adapt to what is on the written page, the book adapts to the student's level of learning and understanding in order to close knowledge gaps.

The e-book tracks what students do and do not know based on what they are reading and how they answer questions, which in turn guides the review and practice components of the program. Based on student responses to the e-book's constant questioning, the program can then predict the optimal path that will maximize student learning. The e-book can also predict what material students will have the greatest difficulty retaining and can devise paths that will help them remember what they have learned.

In addition to its SmartBook, McGraw-Hill also offers LearnSmart Labs, which is a photo-realistic virtual lab that uses adaptive technology to enable students to have a laboratory experience without actually needing a physical lab. With the program, students can practice their experiments in a virtual lab setting, which allows them to make mistakes safely and to learn from their mistakes and their successes.

In LearnSmart Labs, the student is taught lab prep. For instance, students can manipulate virtual bottles of liquids, such as distilled water, on their computer screen and pour them onto dishes or trays. This and other hands-on virtual experiences mirror the realities of a physical lab and reinforce concepts and procedures.

The program also offers lab enhancement, which the company says allows students to learn via adaptive technology that provides a personalized learning path tailored to each student's level of knowledge. In addition, LearnSmart Labs offers lab simulation, which includes a virtual coach in the program who guides the student through the scientific method, emphasizes critical thinking, and responds to mistakes that the student may make.

A program like LearnSmart Labs can help students prepare for their real classes or it can help give a realistic lab experience. The company says the program “allows students and instructors to maximize the valuable time spent in the physical lab” because students will come to lab better prepared and ready to engage in active discussion and learning. Further, for students who have no access to a physical lab, such as students in online courses carried over the Internet, the program “offers the closest thing available to an actual physical laboratory experience, enabling students to put the concepts they have learned in class to the virtual test without requiring access to a bricks-and-mortar lab.” (Belardi, 2013).[5]

Teachers receive immediate reports on the progress of their students, which pinpoint areas needing additional reinforcement, thus allowing real-time feedback on their performance and understanding. Instructors can instantly evaluate the level of content mastery for an entire class or an individual student. Educators can identify the strengths and weaknesses of students and make sure they intervene with lagging students before they become totally lost. One California instructor using the program says that he uses the reports to adapt his teaching to the level of class knowledge. He can ensure that he covers all the topics he needs to cover, and also increase the time spent on those areas that are giving students the most problems (McGraw-Hill, no date).

In its own effectiveness evaluation of LearnSmart, McGraw-Hill points to an independent study of more than 700 anatomy and physiology students at six U.S. institutions. The study found that students using the programs increased their performance by one full letter grade, “with more B students getting As, and more C students getting Bs” (McGraw-Hill, no date).

“I love how it recognizes when I am not understanding a concept and provides the specific text for me to study.”

One student using the program appreciated its adaptive nature: “I love how it recognizes when I am not understanding a concept and provides the specific text for me to study” (McGraw-Hill, no date). Indeed, even if students reach correct answers and show superficial mastery over a topic, the program not only gauges whether students are reaching the right answer, it also is able to measure the confidence of students in their answers and certain subject matter. The programs will then provide them with continued practice until they have reached full confidence with the content material.

5. McGraw-Hill offers instructive videos on SmartBook and LearnSmart Labs, at http://learnsmartadvantage.com/products/smartbook/ and http://learnsmartadvantage.com/products/learnsmart-labs/ respectively.

DreamBox

Another popular adaptive software program is DreamBox Learning, an elementary-school-level math program. According to the company's 2012 white paper on the program, DreamBox provides "a robust curriculum adapted to each individual student through continuous, embedded formative assessment." It claims that intelligent adaptive learning:

- *Adapts* to each learner;
- *Builds* on each learner's prior personal knowledge and goals;
- *Empowers* learners to make self-directed choices;
- *Continually assesses* to form an increasingly rich mental model of the learner;
- *Continually utilizes* assessment data to individualize instruction appropriately.
  (DreamBox Learning, 2012a: 4)

A student using the DreamBox program starts by taking a pretest for the unit of subject matter. The pretest assesses the student's existing knowledge and places him or her at the appropriate level in the curriculum. In assessing a student, the software program can pick up subtleties and nuances beyond simple right or wrong answers.

The program analyzes student answers, based on a wide range of factors (e.g., the number of mouse clicks a student makes), in order to assess the strategy the student uses to answer a question, to see how quickly a student answers a question, to see what mistakes the student has made, to decide whether a student needs extra help, and to decide what is the best next hint to give to the student. The program is capable of capturing 60 distinct behavioral data points as a learner works on a single answer:

> For example, DreamBox captures think time, prep time, and act time. An older or introspective learner might take longer to think about a problem, but might then act quickly; a younger or physical kinetic learner might "fiddle" with the manipulatives to work out his/her response and would therefore have less time to think. This data can be used to dynamically tune responses and further challenges for each learner. (DreamBox Learning, 2012a: 9)

Based on the data collected by the program, the learning process is adapted to the individual needs of the specific student. According to the program's developers, "[t]here are millions of different paths through the DreamBox curriculum, based on each student's needs and interests" (DreamBox Learning, 2012a: 4).

So what exactly happens after a student takes a DreamBox test? If a student shows that he or she does not know the material, "the lesson problems get easier, progressive scaffolding is introduced, and a correct answer may be demonstrated." Further, "the lesson sequence is adjusted to provide additional or parallel lessons that approach the concept in a different way, and then more practice-based lessons are introduced as necessary." If a student continues to have problems, "the program might reintroduce a prior objective, enabling the student to practice it before moving back to the challenging one" (DreamBox Learning, 2012a: 4).

As a student uses the program, it collects information about the student. When a student uses DreamBox for just one minute, the program collects, analyzes, and responds to more than 800 pieces of information about that student and how that student learns. In one hour, the program collects 48,000 pieces of data on that student.

Much of the DreamBox curriculum uses a "gaming" environment. The program uses games and themes to turn lessons, in the words of the company, into "adventures." Students can choose a character for themselves (e.g., dinosaurs, pirates or pets) and story themes, within which the mathematical learning takes place. Also, the program incorporates virtual manipulatives that prod students to explain, discuss, and defend their mathematical thinking. Students are often given a choice of lessons that make use of different manipulatives. The program's data collection capability can pick up whether students "need to be guided toward different manipulatives to deepen their understanding or prepare them for later topics." The program avoids the top-down one-size-fits-all method:

> By letting learners choose the manipulatives that resonate with their learning style (and encouraging them to expand their boundaries), DreamBox provides a balanced diet without forcing the same problems in the same order to be learned in the same way by every student. Some learners like to sample the different manipulatives; others want to push one to its limits. (DreamBox Learning, 2012a: 11)

[A]daptive software like DreamBox can not only differentiate instruction between students, it allows the individual student to work at different grade levels based on his or her understanding.

Because students catch on to different subject matter topics at different rates, adaptive software like DreamBox can not only differentiate instruction between students, it allows the individual student to work at different grade levels based on his or her understanding. Thus, for example, "a student could be working in the first-grade curriculum for addition and subtraction, but in the second-grade curriculum for place value" (DreamBox Learning, 2012a: 4).

Such differentiation of instruction would be very difficult, if not outright impossible, in traditional whole-class-lecture classrooms.

In addition, DreamBox can collect a wide range of data on students because the program uses constructive-response questions, which ask students to apply their knowledge to construct an answer, and which allows for variations in responses and multiple ways to get to the right or wrong answer. Thus, "different wrong answers show different deficiencies in the student's mental model and therefore he/she might require different remediation by DreamBox" (DreamBox Learning, 2012a: 9).

The program's data collection not only helps adapt instruction to the individual needs of the student, it also assists teachers in a variety of ways. In traditional classrooms, teachers have little ability to discern which groups of students are having similar problems. DreamBox, however, uses data-mining techniques to segment students so that it can identify groups of students based on their understanding or lack of understanding of subject-matter material. Teachers can then target their intervention to groups of students having the same problems understanding the material. In addition, students can be grouped for specific projects, small-group instruction, or enrichment activities for advanced students.

The program also generates a variety of reports on student learning that can assist teachers in perfecting their instructional methods:

> DreamBox provides concept-level reports showing where students are proficient (based on embedded assessments), what they are currently learning or have learned through DreamBox lessons, and what they still need to learn. DreamBox also provides alerts when a student needs one-on-one help from the teacher, or when he/she is learning inefficiently.
>
> Teachers also get "at-a-glance" information on their whole class. This can assist in setting up student groups for differentiated instruction or guided math lessons. And administrators get reports on concept proficiency, classroom and school progress, DreamBox usage, and license utilization. (DreamBox Learning, 2012a: 11)

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For principals and other education leaders, DreamBox holds out the possibility of showing not just the performance of students individually or as a whole class of students, but also the performance of individual teachers. As the DreamBox white paper notes, the program's data can be used with demographic data systems "to measure progress according to teacher, school, reporting subgroups, and so forth" (DreamBox Learning, 2012a: 11). Teachers can then be evaluated on their performance based on a rich source of data about the learning of their students.

For parents, the program provides the same data reports that teachers receive. Because these reports are generated immediately, parents can really know what their children did in school on a given day. Parents can then give feedback to their children when it is most timely and effective.

For parents, the program provides the same data reports that teachers receive … [P]arents can really know what their children did in school on a given day …

DreamBox has had notable success at schools in the United States. At the Rocketship Mateo Sheedy charter elementary school, which is located in urban San Jose, California, DreamBox is one of a number of interactive adaptive learning software programs that the school uses. Rocketship serves a challenging student population, with 95 percent listed as socio-economically disadvantaged, 90 percent Hispanic, and 63 percent who are not fluent in English (Education Results Partnership, 2012).

John Danner, co-founder and CEO of Rocketship Education, observes that for such students, "[u]nfortunately, there is very little chance that they'll receive instruction that is at their 'just right' developmental level in a traditional classroom" (DreamBox Learning, 2012b: 2). In contrast to the limitations of instructional methods in regular classrooms, Charlie Bufalino, Rocketship's online learning specialist, says that DreamBox meets the needs of the individual student:

> It's not only the way DreamBox gathers information, it's the way that information is used to adapt learning paths. DreamBox makes adjustments on a problem-by-problem basis. That means DreamBox can help kids optimize strategies so if numbers are being built in an efficient way, they're prompted to do it again more efficiently. That helps students develop the strategies they'll need when faced with more difficult tasks later on. …
>
> Once you acknowledge that students have individualized needs and that instruction needs to be differentiated in order for them to succeed, the ability for technology like DreamBox to adapt becomes even more critical. Gaps in knowledge vary from student to student and utilizing DreamBox enables teachers to be more effective in the classroom. (DreamBox Learning, 2012b: 2-3)

DreamBox has been used at Rocketship Mateo Sheedy since 2010. The use of DreamBox and other adaptive learning software has contributed significantly to excellent results at the school. In 2012, more than 90 percent of students in every grade level from second through fifth scored at or above the proficient level on California's standardized math test. In the fourth grade, an incredible 99 percent of students scored at the proficient level or above on the state math exam (Education Results Partnership, 2012). "Proficient" is usually defined as having mastery of the particular subject matter. These results top the achievement of nearby schools in affluent Palo Alto, such as

Rocketship Mateo Sheedy, San Jose. Image from http://www.rsed.org/mateosheedy/our-school.cfm

Addison Elementary, whose students are mostly white and Asian, and where less than 10 percent are socio-economically disadvantaged.

As LearnSmart and DreamBox demonstrate, interactive adaptive learning educational software has become very sophisticated. Schools that have incorporated such software into their instructional programs have seen marked benefits. But how are schools really using this adaptive learning software?

The approach most commonly used to adopt adaptive technology in classrooms is applied through a process called blended learning. The Clayton Christensen Institute for Disruptive Innovation, formerly known as the Innosight Institute, defines blended learning as “a formal education program in which a student learns at least in part through online delivery of content and instruction with some element of student control over time, place, path, and/or pace and at least in part at a supervised brick-and-mortar location away from home” (Staker and Horn, 2012).

The Khan Academy advocates one blended-learning variant called the “flipped classroom”. Students in a “flipped classroom” view instructional content, such as Khan’s non-adaptive videos, online on their computers at home or at other non-school sites outside of the regular classroom. In class they use the interactive adaptive learning software to do exercises. The results of their in-class efforts are relayed to their teachers in real time to inform the teachers’ intervention strategies.

Los Altos School District

Khan has piloted his “flipped classroom” model and his Khan Academy math program in several schools, including a number in the Los Altos school district in California. Initially, Khan Academy methods of the flipped classroom were used in a handful of selected fifth- and seventh-grade classes as a trial for the district. Students viewed the Khan videos at home and used the online adaptive learning software program during class time.

The Los Altos school district is generally viewed as an area with children from high-income families. That perception is not entirely accurate. While there is a stratum of students from advantaged backgrounds, there is another stratum of students who come from lower-income families. Because of local conditions, fifth graders came mainly from advantaged families, while there is a more diverse mix of students from all income backgrounds in the seventh grade. Khan Academy helped students from both strata.

Among Los Altos fifth graders, 91 percent had already achieved at the proficient level or above on California's standardized math exam in the year prior to the use of Khan Academy program. In the year that Khan Academy was implemented, 96 percent of fifth graders tested at the proficient level or above. According to Sal Khan:

> It did decisively prove to the district that despite the fact that our software was still at a nascent state and that we weren't teaching to the test, the experiment was definitely not doing any harm. In light of the test results, coupled with the positive feedback from teachers, students, and parents, the board decided to use the Khan Academy as part of the math curriculum for all fifth- and sixth-grade math classes in the district for the following school year. (Khan, 2012: 167)

It was among the more diverse seventh graders, however, where there was more significant improvement. Comparing the performance levels for pilot seventh-grade classrooms between 2010, the year before Khan Academy was implemented, and 2011, the year those classrooms used Khan Academy, the percentage of students performing at or above proficient levels increased from 23 to 41 percent. Also, the percentage of students performing "below basic or far below basic," which are the lowest performance levels, dropped from 29 to 12 percent (Khan Academy, 2013).

Los Altos district superintendent Jeff Baier notes that "Khan Academy got students the instruction and the learning they needed at the level they were at and at the time they needed it." For teachers, he said, they "could know at any moment in time, in real time, where a student was soaring successfully and where a student was struggling" (Khan Academy Schools, June 25, 2012). Teachers can view the progress of every student in their class on their computer dashboards. They can see all the Khan Academy exercises that students have attempted.

So, for instance, teachers can click on the topic of "systems of equations" and the list of their students and a color-coded table of information appear, telling the teacher whether each individual student is proficient, needs review, or is struggling. Teachers can then target their intervention strategies and activities based on this data. The teacher can click on the struggling student and see the results of the last set of problems on which the student worked. The data chart on the problems not only tells the teacher whether the student solved a problem correctly or not, but how much time a student took to answer the problem and whether or not he or she needed hints or rewatched a Khan video for assistance.

The Khan Academy software also gives teachers a summary chart that breaks down the performance of a teacher's entire class on a specific topic. For instance, for the topic of "systems of equations," the chart will show how many students have not started the exercises, how many are proficient, how many are reviewing the material, and how many are struggling. By clicking on the bar for struggling students, the software will list the names of those students. The teacher can then decide to help those struggling students or could ask the proficient students to work with them using a cooperative-learning strategy.

Alyssa Gallagher, assistant superintendent for Los Altos, says that the Khan Academy software gives teachers the information they need to avoid wasting their time teaching skills that students already know. Instead, "teachers can adjust their time accordingly to meet their students' needs" (Khan Academy Schools, June 25, 2012).

[S]chool officials say that the required curriculum is covered more quickly, which leaves more time for other activities such as project-based learning.

Because Khan Academy promotes efficient use of student and teacher time, school officials say that the required curriculum is covered more quickly, which leaves more time for other activities such as project-based learning. Teachers say that Khan Academy has made them more effective.

Kelly Rafferty, a Los Altos teacher, said that before Khan Academy programs she tried to meet all her students at their individual levels, but she never felt that she was accomplishing that goal. That all changed when the Khan Academy program was implemented in her classroom:

> So when Khan Academy came, within the first two weeks I could see the kids who were struggling. Some kids were already passing module after module, moving into algebra, moving into places that I hadn't gotten to with them yet. I just looked at this and said, "Oh my goodness, this is amazing." And I was able to pull in small groups of kids to help boost them up, find out where their levels were that were way below fifth grade at the time, and it finally gave me the freedom to know that I was teaching everybody and that nobody at any time was bored. (Khan Academy Schools, June 25, 2012)

Another Los Altos teacher, Kami Thordason, says that before Khan Academy she could go for weeks before finding out that a student did not understand a concept from two chapters ago. With the real-time data from Khan's adaptive learning software, "you can go in and save the day" (Khan Academy Schools, June 25, 2012).

Teacher Courtney Cadwell says that because Khan Academy programs adapt to the level of understanding of the student, high-achieving students can race from subject to subject, explore topics, and not be held back by non-adaptive whole-class instruction. For struggling students, who are having difficulty with basic math that they did not master in previous grades, Khan Academy's adaptivity "gives them a chance to go back and fill in those gaps in their understanding and move forward on a firmer foundation" (Khan Academy Schools, June 25, 2012). This new model of instruction gives students the opportunity for one-on-one and small-group instruction with the teacher, which is difficult under whole-class instruction.

When parents e-mail teacher Ellen Kraska and tell her that their child is having trouble with certain problems, Kraska can immediately access the data from Khan Academy to see what problems the student is working on at that time and what problems are giving the student difficulty. She can then plan her lesson for the next day for that student based on those difficulties. "My teaching is more informed and more targeted," says Kraska (Khan Academy Schools, June 25, 2012).

In 2010, a little more than 100 students in the Los Altos school district used the Khan Academy programs. Because the program significantly increased the rate of proficiency among those students, the district has expanded the number of students using Khan Academy to more than 1,000.

Beyond these preliminary results, the Khan Academy is working with the Gates Foundation and a team of third-party researchers to study the effectiveness of the program. Three studies are currently underway, including: 1) an impact study to determine the effectiveness of Khan Academy programs on student learning at and beyond grade-level concepts; 2) an implementation study to determine which pedagogies are most effective for different types of classrooms; and 3) a cost study to find out the various costs associated with implementing the program (Khan Academy, 2013).

Challenges

Teachers' unions and many individual teachers see adaptive technology as a means to remove teachers from the classrooms and replace them with computers.

Despite the success of some of these initial efforts, a number of challenges have begun to emerge that potentially stand in the way of implementation of adaptive technology. A primary potential challenge to adaptive technology comes from teachers. Teachers' unions and many individual teachers see adaptive technology as a means to remove teachers from the classrooms and replace them with computers. Although it is true that adaptive technology can allow more students to be overseen by fewer teachers, the technology also allows for quicker movement through the assigned material. In a flipped classroom setting for example, students view lectures outside of class time which allows the teachers to spend less time repeating materials and greater time for teacher-led alternative learning activities or discussions, all of which occur away from technology. Nonetheless, there is growing resistance to adaptive technology from individual teachers and related groups.

Another concern is privacy. Adaptive technology functions by gathering data on users from baseline tests and their progression through the program, and comparing it not only to fellow students in the classroom but potentially to thousands or millions of other students, past and present, in an attempt to identify learning patterns. Proponents of adaptive technology have argued that these learning profiles are similar to student transcripts, but parent groups have nonetheless expressed concerns about the availability of confidential school data to third parties (Fletcher, 2013).

One of the final hurdles is the cost of the new adaptive technology. In order to be effectively implemented, schools require not only the software for students but also the hardware. For example, many McGraw-Hill courses start at $35, while the SmartBook e-book version of the course costs $75 to $100.[6] Although it would be expected that a school or school board could achieve some economies of scale in their purchasing, the fact remains that for the software licenses alone each school is likely dedicating tens of thousands of dollars per course. This cost is then compounded by the need for schools to provide computers, laptops or tablets that can adequately run the software in sufficient numbers that each student is capable of accessing it. Finding funding for these initiatives is a challenging prospect in a climate of increasing budget constraint.

6. Sample prices retrieved August 6, 2013 from http://learnsmartadvantage.com/course-books/.

Conclusion

In his recent book *The One World School House*, Sal Khan protests against the so-called Prussian model of instruction, which most people remember as the teacher lecturing to a whole class of students (Khan, 2012: 181). While the Prussian model worked for many students, some fell behind and never caught up with the rest of the class, while others got bored and lost motivation because the class was moving too slowly for them. As the examples of adaptive learning software described in this paper demonstrate, future students do not have to be lost or bored. Instead, it could be possible for all students to reach their full academic and life potential.

Salman Khan, founder of Khan Academy. Image from http://www.khanacademy.org

Technology has progressed so that students do not have to get stuck on a problem or a topic, with little or no help from a teacher until it is too late to do any real good. Knowledge gaps can be plugged, skills kept sharp, and teaching made more individualized and effective. Students will be more likely to say “Aha!” than “I give up!”

Although the technology is now available to change the face of education and learning in countries across the world, it is still important to recall a sobering fact. It is government that perpetuates the Prussian model of instruction through the direct provision of education in government-run schools as well as through the larger education regulatory apparatus. Indeed, there are many internal incentives for governments to keep the old system rather than change to a new and better one. Thus, as one recent report on the Khan Academy noted:

> Only by breaking the government’s stranglehold on the school system will innovators and entrepreneurs like Khan be able to change the government’s favored method of education delivery on a system-wide scale. (Izumi and Parisi, 2013: 23)

This potential revolution in education holds numerous avenues for research by the Fraser Institute and the Barbara Mitchell Centre for Improvement in Education. There are two key areas requiring additional research with respect to adaptive learning in Canada. First, better quantitative, empirical research needs to be completed regarding the actual benefits from adaptive technology and the keys to success with respect to implementing and using it.

The second area, and the one most related to the work of the Fraser Institute, pertains to policy barriers for the introduction of technology. For example, one of the most relevant and immediate questions from a policy perspective relates to quantifying the barriers preventing schools, educators, and education entrepreneurs from introducing and implementing adaptive technology on a broader scale. Other questions, such as the cost of potential technologies given current budget constraints, teacher training, and quality control, are also relevant.

Other potential avenues of research on the impact of adaptive technology relate to homeschooling and education in remote and rural communities, where educational options are limited. The ability to bring into a single enhanced classroom those who suffer from substandard educational options (e.g., schools in the Far North or on aboriginal reserves), or who currently learn outside of the traditional education system, is an obvious area for additional research.

There are a host of other technology-related issues, such as the impact of MOOCs on post-secondary education, that require additional analysis.[7]

The struggle to change the way we educate our children is a question, not simply of developing a better mousetrap, but of opening up the marketplace to those mousetraps. As Khan himself observes, "the conventional educational establishment seems oddly blind (or tragically resistant) to readily available technology-based solutions for making education not only better but more affordable, [and] accessible to far more people in far more places" (Khan, 2012: 181). Policy and technology must work together so that that all children can benefit.

7. A recent article by the National Center for Policy Analysis (2013) touches on the revolutionary potential of blended-learning educational methods in Higher Education.

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