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Big Data for Education: Data Mining, Data Analytics, and Web Dashboards

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EXECUTIVE SUMMARY

Twelve-year-old Susan took a course designed to improve her reading skills. She read short stories and the teacher would give her and her fellow students a written test every other week measuring vocabulary and reading comprehension. A few days later, Susan's instructor graded the paper and returned her exam. The test showed that she did well on vocabulary, but needed to work on retaining key concepts.

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In the future, her younger brother Richard is likely to learn reading through a computerized software program. As he goes through each story, the computer will collect data on how long it takes him to master the material. After each assignment, a quiz will pop up on his screen and ask questions concerning vocabulary and reading comprehension. As he answers each item, Richard will get instant feedback showing whether his answer is correct and how his performance compares to classmates and students across the country. For items that are difficult, the computer will send him links to websites that explain words and concepts in greater detail. At the end of the session, his teacher will receive an automated readout on Richard and the other students in the class summarizing their reading time, vocabulary knowledge, reading comprehension, and use of supplemental electronic resources.

In comparing these two learning environments, it is apparent that current school evaluations suffer from several limitations. Many of the typical pedagogies provide little immediate feedback to students, require teachers to spend hours grading routine assignments, aren't very proactive about showing students how to improve comprehension, and fail to take advantage of digital resources that can improve the learning process. This is unfortunate because data-driven approaches make it possible to study learning in real-time and offer systematic feedback to students and teachers.

In this report, I examine the potential for improved research, evaluation, and accountability through data mining, data analytics, and web dashboards. So-called "big data" make it possible to mine learning information for insights regarding student performance and learning approaches.[1] Rather than rely on periodic test performance, instructors can analyze what students know and what techniques are most effective for each pupil. By focusing on data analytics, teachers can study learning in far more nuanced ways.[2] Online tools enable evaluation of a much wider range of student actions, such as how long they devote to readings, where they get electronic resources, and how quickly they master key concepts.

[1] James Manyika, Michael Chui, Brad Brown, Jacques Bughin, Richard Dobbs, Charles Roxburgh, and Angela Byers, "Big Data: The Next Frontier for Innovation, Competition, and Productivity," McKinsey Global Institute, May, 2011.
[2] Felix Castro, Alfredo Vellido, Angela Nebot, and Francisco Mugica, "Applying Data Mining Techniques to e-Learning Problems," *Studies in Computational Intelligence*, Volume 62, 2007, pp. 183-221.

The Value of Systematic, Real-Time Data

The development of computerized learning modules enables assessment of students in systematic, real-time ways. Data mining and data analytic software can provide immediate feedback to students and teachers about academic performance. That approach can analyze underlying patterns in order to predict student outcomes such as dropping out, needing extra help, or being capable of more demanding assignments. It can identify pedagogic approaches that seem most effective with particular students.[3]

For example, an online high school curriculum known as Connected Chemistry helps students learn key concepts in molecular theory and gasses. Chemistry is made up of many elements which interact in complex ways to form chemical systems. The program helps pupils understand how submicroscopic particles relate to macroscopic phenomena.

> In relating volume and pressure of gases, teachers found that half the students were not able to use math to summarize key relationships and measure how different volume levels affected gas pressure.

Employment of this software allows teachers to mine learning patterns to see how students master chemistry, statistics, experimental designs, and key mathematical principles. They do this through embedded assessment tools as well as pre- and post-test evaluation. The results indicate that students go through particular steps in developing mathematical models of complex chemical processes. In relating volume and pressure of gases, teachers found that half the students were not able to use math to summarize key relationships and measure how different volume levels affected gas pressure.[4]

Researchers Joseph Beck and Jack Mostow use intelligent tutor software to study student reading comprehension and determine whether re-reading an old story helped pupils learn words better than reading a new story. Based on analysis of reading time, word knowledge, reading mistakes, and help requests, they found that "re-reading a story leads to approximately half as much learning as reading a new story."[5]

In general, school systems place a high priority on formative assessment, meaning feedback designed to improve the learning process. This includes measurement of discrete subjects, such as concepts mastered, skills realized, and time spent on particular assignments.[6] Feedback typically is embedded in the instructional process so that students and teachers get real-time results on what is being learned and can monitor overtime performance.

Computers make it possible to alter test items based on how pupils perform on

[3] U.S. Department of Education Office of Educational Technology, "Enhancing Teaching and Learning Through Educational Data Mining and Learning Analytics," 2012.
[4] Sharona Levy and Iri Wilensky, "Mining Students' Inquiry Actions for Understanding of Complex Systems," *Computers & Education*, Volume 56, 2011, pp. 556-573.
[5] Joseph Beck and Jack Mostow, "How Who Should Practice: Using Learning Decomposition to Evaluate the Efficacy of Different Types of Practice for Different Types of Students," *Proceedings of the 9th International Conference on Intelligent Tutoring Systems*, 2008, pp 353-362.
[6] Ryan Baker, "Data Mining for Education," Barry McGaw, Penelope Peterson, and Eva Baker, eds., *International Encyclopedia of Education*, Third Edition, Oxford, United Kingdom: Elsevier, 2012.

earlier questions. Testers can try out different alternatives and observe how students respond. Through "branching" items, they can probe more deeply in certain areas and thereby provide more individualized performance information.[7] For example, if students get all the questions right (or wrong), it establishes a ceiling (or a floor) regarding their knowledge levels. This allows the assessment to move to higher or lower skill mastery levels so that the evaluation can determine where students need more help.[8]

With the advent of computerized instruction, scholars argue that the specific types of feedback are crucial for improving learning. For example, David Nicol and Debra MacFarlane-Dick outline seven principles of effective feedback. They include clarifying what good performance is, facilitating self-assessment in learning, delivering high quality information to students, promoting peer dialogue around learning, encouraging positive motivations, showing how to close gaps between current and desired performance, and providing information to teachers on effective feedback.[9]

It is possible to take these principles and evaluate learning in more detailed ways. Vincent Aleven and his colleagues at Carnegie Mellon University run controlled experiments through Intelligent Tutoring Systems. These experiments provide tools through which professors can develop online tutorials in areas such as chemistry and physics, and compile pre-test and post-test assessments plus detailed records of interactions between students and electronic tutors.

These types of computer tutorials can evaluate problem-solving approaches and provide feedback along the instructional path. The system sends error messages if the student follows an incorrect approach and provides answer hints if requested by the student. Instructors can get a detailed analysis not just of whether the student reached the final answer correctly, but how they solved the problem.[10]

Research by James Theroux of the University of Massachusetts at Amherst found that embedded assessment "engages and satisfies students at a higher level than do average courses and presents a more realistic and integrated view of business decision making."[11] A clear majority of pupils preferred the online over a traditional approach and felt the course materials were very applicable to real life. The cases helped faculty assess the degree to which students grasped management

[7] David J. Weiss, "The Stratified Adaptive Computerized Ability Test," Minneapolis: University of Minnesota Computerized Adaptive Laboratory, 1973.
[8] Lawrence Rudner, "The Power of Computerized Adaptive Testing," Graduate Management News, 2011.
[9] David Nicol and Debra Macfarlane-Dick, "Formative Assessment and Self-Regulated Learning: A Model and Seven Principles of Good Feedback Practice," *Studies in Higher Education*, Volume 31, number 2, 2006, pp. 199-218.
[10] Vincent Aleven, Jonathan Sewall, Bruce McLaren, and Kenneth Koedinger, "Rapid Authoring of Intelligent Tutors for Real-World and Experimental Use," *Human-Computer Interaction Institute*, Pittsburgh, Pennsylvania: Carnegie Mellon University, 2006.
[11] James Theroux, "Real-Time Case Method: Analysis of a Second Implementation," *Journal of Education for Business*, July/August, 2009, pp. 367-373.

principles and gave them an opportunity to apply student feedback based on actual corporate experiences.

Researcher Paulo Blikstein studied college students in a computer programming class to see how they solved a modeling assignment. The NetLogo software logs all user actions from button clicks and keystrokes to code changes, error messages, and use of different variables. Blikstein found that error rates progressed in an "inverse parabolic shape" as students tried things and made a lot of mistakes initially, and then progressed through problem solving until they had developed the correct model.[12]

Some instructors use an interactive "web of inquiry" site to teach scientific analysis. The website enables students to test hypotheses, learn the language of science, design experiments, code variables, collect data, analyze data, and develop tables.[13] Online advice helps students with each stage of scientific inquiry and helps them formulate and test their ideas.

… [M]ost instructors believed students were engaged with these types of assignments because they enjoyed their collaborative and interactive nature. As opposed to looking for general Internet information on their own, students had to talk with one another to fulfill the assignment.

WebQuest is an online activity that teachers employ to send students to the web to find information or solve particular problems. It is designed to train pupils in skills of information acquisition and ways to evaluate online materials. Students are given particular tasks and use the Internet to seek and evaluate alternative sources of information.

A detailed survey by scholars Robert Perkins and Margaret McKnight of 139 teachers who attended an instructional technology conference devoted to WebQuest found that most instructors believed students were engaged with these types of assignments because they enjoyed their collaborative and interactive nature.[14] As opposed to looking for general Internet information on their own, students had to talk with one another to fulfill the assignment.

Researchers have used the Social Networks Adapting Pedagogical Practice (SNAPP) to investigate student interactions based on forum postings. This software visualizes pupil exchanges in order to find disconnected students who are at risk of not completing the course, high versus low performing students, before and after snapshots of teacher interventions, and benchmarking student progress. An analysis by education evaluations found that the program "is extremely effective in promoting reflection on teaching activities and rapidly assessing the overall effectiveness of the pedagogical intent post course completion."[15] Those who participated frequently in online forums were more

[12] Paulo Blikstein, "Using Learning Analytics to Assess Students' Behavior in Open-Ended Programming Tasks," *Proceedings of the First International Conference on Learning Analytics and Knowledge*, New York: ACM Press, 2011, p. 115.
[13] Leslie Herrenkohl and Tammy Tasker, "Pedagogical Practices to Support Classroom Cultures of Scientific Inquiry," *Cognition and Instruction*, Volume 29, number 1, 2011, pp. 1-44.
[14] Robert Perkins and Margaret McKnight, "Teachers' Attitudes Toward WebQuests as a Method of Teaching," Charleston, South Carolina: College of Charleston School of Education, undated paper.
[15] Shane Dawson, Aneesha Bakharia, Lori Lockyer, and Elizabeth Heathcote, "'Seeing' Networks: Visualising and Evaluating Student Learning Networks," Australian Learning and Teaching Council, 2011, p. 4.

engaged and performed better in the course.

Predictive Assessments

Other ways that technology enables learning is through predictive and diagnostic assessments. The former seek to evaluate how students will perform on standardized tests, while the latter emphasizes which instructional techniques work for individual students and the best ways to tailor learning. A virtue of nuanced digital evaluation is that it provides students with information relevant to learning and performance.

Online predictive assessments work by focusing on performance. McGraw-Hill has an Acuity Predictive Assessments tool that provides "an early indication of how students will likely perform on state NCLB assessments."[16] It assesses the gap between what students know and what they are expected to know on standardized tests and suggests where students should focus their time in order to improve exam performance.

Similarly, the company's Acuity Diagnostic Assessment tool helps "teachers probe student understanding of state standards, grade-level expectations, and specific skills, and quickly diagnose their strengths and instructional needs."[17] By following how pupils solve problems and evaluate information, this tool provides guidance regarding preferred learning styles and gears instruction to that preference.

Follow-up research has found that some students like to go through problem-solving step-by-step and analyze material in a linear manner. Others prefer visual or graphical presentation and integrating information in a non-linear fashion. Assessment of learning styles is crucial to personalization and tailoring instructional presentation in the most effective manner. Digital tools that help parents and teachers understand student learning approaches is vital to educational attainment.

Schools in sixteen states now employ data mining techniques to identify at-risk students. Using prediction models based on truancy, disciplinary problems, changes in course performance, and overall grades, analysts have discovered that they have a reasonable probability of identifying students who drop out. For example, the school district in Charlotte-Mecklenburg County, North Carolina found their "risk-factor scorecard" showed who was at-risk and in need of special assistance.[18]

Analysts Leah Macfadyen and Shane Dawson developed predictive modeling to determine which students were likely to fail a class. They examined fifteen

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[16] McGraw-Hill, "Building the Best Student Assessment Solution," New York: Acuity, 2009.
[17] McGraw-Hill, "Building the Best Student Assessment Solution," New York: Acuity, 2009.
[18] Michelle Davis, "Data Tools Aim to Predict Student Performance," *Education Week Digital Directions*, February 8, 2012.

variables such as the number of discussion messages posted, time online, visits to course chat area, number of emails sent, number of assessments completed, and time spent on the assignments. By finding who was most engaged with and connected to the class, their model identified eighty-one percent of failing students.[19]

Arizona State University has an eAdvisor system in which freshmen choose one of five broad areas of study such as arts and humanities or science and engineering with designated courses of study. If students perform poorly in required courses or miss a course in a particular sequence, the software identifies them as "off-track" and sends them to an advisor who helps them select another area that may be better suited to their areas of interest.[20]

Austin Peay State University employs a "Degree Compass" program that provides course recommendations based on a one to five scale linked to their relevance to the student's chosen major, high school transcript, standardized test performance as well as their predicted course success based on other college classes they have taken. This helps students choose courses that make sense for them and enable them to finish degree requirements.[21]

Dashboards compile key metrics in a simple and easy to interpret interface so that school officials can quickly and visually see how the organization is doing.

Tracking Performance Through Dashboards and Visual Displays

Armed with statistical information compiled from various digital systems, a number of schools have developed dashboard software and data warehouses that allow them to monitor learning, performance, and behavioral issues for individual students as well as the school as a whole. Dashboards compile key metrics in a simple and easy to interpret interface so that school officials can quickly and visually see how the organization is doing. Administrators automatically update dashboards based on data stored in student information systems. Software combines data from various streams to present a clear and comprehensive overview of school operations.[22]

As an example, DreamBox is a dashboard that aggregates data for administrators. For different concepts, it summarizes proficiency data for each grade level in particular schools. It shows what percentage of students in the first grade have completed a concept mastery, what percent are in progress, and what percent have not started mastery exercises. At a glance, administrators can compare each grade and see overall how well their students are performing. Areas

[19] Leah Maacfadyen and Shane Dawson, "Mining LMS Data to Develop an 'Early Warning System' for Educators," *Computers & Education*, Volume 54, 2010, pp. 588-599.
[20] Marc Parry, "Pleased Be eAdvised," *New York Times Education Life*, July 22, 2012, p. 25.
[21] Marc Parry, "Pleased Be eAdvised," *New York Times Education Life*, July 22, 2012, p. 26.
[22] Jonathan Supovitz and John Weathers, "Dashboard Lights: Monitoring Implementation of District Instructional Reform Strategies," Philadelphia: University of Pennsylvania Consortium for Policy Research in Education, December, 2004.

that are underperforming can be given additional help so they can do better.[23]

The United States Department of Education has a national dashboard at http://dashboard.ed.gov/dashboard.aspx which compiles public school information for the country as a whole. According to the website, the dashboard uses indicators that "are focused on key outcomes. The indicators chosen for the Dashboard are select factors that the Department believes will, if the country demonstrates progress, make significant contributions to reaching our 2020 goal."[24]

Among the items measured in this dashboard are percentage of 25 to 34 year-olds who completed an associate's or higher degree (and whether this number was up or down from earlier periods), 3 and 4-year olds enrolled in preschool, 4th grade reading and math proficiency in National Assessment of Educational Progress, 18 to 24 year olds enrolled in colleges and universities, and number of states using teacher evaluation systems that include student achievement outcomes.

The state of Michigan has a dashboard at http://www.michigan.gov/midashboard that ranks performance as improving, staying the same, or declining in various areas. The dashboard focuses on fourteen indicators for student outcomes (reading proficiency and college readiness), school accountability (meeting federal progress metrics), culture of learning (reports of school bullying and free lunch participation), value for money (number of districts with ongoing deficits), and post-secondary education (tuition as percentage of median family income, retention rates, and graduation rates).[25]

Chicago Public Schools uses software called IMPACT, standing for Instructional Management Program and Academic Communications Tool.[26] It tracks student performance in four areas: student information management; curriculum and instructional management; student services management; and a gradebook for parents and students. It is available to students, parents, teachers, administrators, and support staff through the school system's website at www.cps.edu. Teachers can develop and publish lesson plans through this site and registered users can access standardized test results, benchmark assessments, instructional resources, and discussion forums.

The Beaverton, Oregon School District combines a VersiFit data warehousing system from Versifit.com with an eSIS student information system produced by Aalsolutions.com. The school's chief information officer Steven Langford says that school officials "took the data out of the student information system and put it into a web-based portal for analysis…. I can instantly see real-time discipline information, such as in-school and out-of-school suspensions, unexcused and

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[23] U.S. Department of Education Office of Educational Technology, "Enhancing Teaching and Learning Through Educational Data Mining and Learning Analytics," 2012, p. 20.
[24] See U.S. dashboard at http://dashbard.ed.gov/dashboard.aspx.
[25] See state dashboard at http://www.michigan.gov/midashboard/0,1607,7-256-58084---,00.html. Other states having dashboards include Hawaii at http://castlefoundation.org/educationdashboard/ and New Mexico at http://www.ped.state.nm.us/stars/index.html.
[26] See website description at http://impact.cps.k12.il.us/faq.shtml.

excused absences, demographic information, and so on. We can drill down into metrics to get to the level of the individual student. Then we can design intervention and scaffolding to better help each student get to the next level."[27]

However, most of these dashboards are not very detailed in terms of individualized learning progress. For example, the information systems outlined above review data on overall school trends and individual scores, but not material on what students learn, how they acquire knowledge, and what materials and approaches work best for them. This limits the usefulness of the data collection for learning purposes.

Higher education dashboards often feature a wider array of material. For example, a dashboard compiled by the Educause Center for Applied Research argues that colleges and universities should rely on indicators measuring resources, risk levels, input graphs, the institutional pulse, the opportunity gauge, an environmental scan for pressure points, trend statistics, and a red-flag report of possible problems.[28]

Yet many barriers complicate the achievement of these benefits. In general, too much of contemporary education focuses on education inputs, not outputs.

The University of California at San Diego has dashboards relevant for various parts of the organization. There is a financial dashboard that focuses on financial and capital resources. There is a faculty one that keeps tabs on sponsored research. Each draws on data from university systems and displays and updates the information as desired by the user. Recently, the university added an energy dashboard at http://energy.ucsd.edu/, that measures consumption and ways the campus is saving energy.

These and other types of tracking systems improve accountability in the educational arena. They take information that already exists in most schools, integrate it into a simple user interface, and graphically display trends in an easy-to-analyze manner. This helps school officials understand what is happening within their districts and policymakers assess the linkages between inputs and outputs.

Overcoming Operational and Policy Impediments

There are many opportunities to advance learning through data mining, data analytics, and web dashboards and visual displays. Technology enables the use of new approaches to formative and predictive assessment. Both students and teachers (as well as school administrators) can get systematic feedback in real-time and use that material to improve academic performance.

Yet many barriers complicate the achievement of these benefits. In general, too much of contemporary education focuses on education inputs, not outputs. Schools are measured based on seat-time, faculty-student ratios, library size, and

[27] Christine Weiser, "Dashboard Software," *Scholastic*, September, 2006.
[28] Elazar Harel and Toby Sitko, "Digial Dashboards: Driving Higher Education Decisions," Boulder, Colorado: Educause Center for Applied Research, September 16, 2003.

dollars spent educating students. Accreditors employ these metrics to determine which schools are providing the highest level of resources for students and are therefore in a position to do the most effective job.

Even though this information is important, it misses the end result of education, which is producing well-trained and knowledgeable graduates. Schools and accreditors should emphasize outputs as well as inputs. Educational institutions should be judged not just on what resources are available, but whether they do a good job delivering an effective education. Real-time assessment means that elementary and secondary schools can evaluate how much students have learned and how much progress there has been towards board educational objectives.

Reformers Michael Horn and Katherine Mackey describe the importance to moving to a focus on outcomes.[29] They recommend that education providers be judged on student performance, with reimbursement tied to performance measures. Real learning should generate bonuses for schools because it indicates effective programs. Students should be allowed to demonstrate competency on their own schedule, as opposed to artificially-derived school years.

Schools face a situation where they need to improve the overall accountability of their operations. In an environment of considerable public, media, and policymaker scrutiny and scarce resources, educational institutions must get better at data collection, record-keeping, analysis, and reporting. More detailed information for schools is being generated, and this provides the opportunity for instantaneous feedback on school activities. Parents and teachers can assess what is happening in the classroom, while administrators and policymakers can evaluate learning and achievement.

Data analytics help in each of these areas. Digital systems enable real-time assessment and more effective systems for mining information. They help public officials evaluate what is happening in schools and what kinds of results are being achieved. This increases learning, transparency, and accountability, and makes it easier to evaluate trends in educational institutions.

The key is overcoming barriers of the use of new assessment techniques. The biggest obstacles are building data sharing networks. Many schools have information systems that do not connect with one another. There is one system for academic performance, another for student discipline, and still another for attendance. The fragmented nature of technology inhibits the integration of school information and mining for useful trends.

In addition, educational institutions need to format data in similar ways so that results can be compared.[30] Too often there is inconsistent terminology or coding on

[29] Michael Horn and Katherine Mackey, "Moving from Inputs to Outputs to Outcomes: The Future of Education Policy," Mountain View, California: Innosight Institute, June, 2011.
[30] Cristobal Romero and Sebastian Ventura, "Educational Data Mining: A Review of the State-of-the-Art," *IEEE Transactions on Systems, Man, and Cybernetics*, Volume XX, 2010.

issues related to school dropouts or graduation. Information entered into data systems must be easily understood and coded in comparable ways. Working on common semantics and metrics will allow system administrators to aggregate material and analyze the information.[31]

... [S]chools must understand the value of a data-driven approach to education. Having performance systems will contribute to informed decision-making.

Finally, schools must understand the value of a data-driven approach to education. Having performance systems will contribute to informed decision-making. It will allow administrators to identify trends, pinpoint problem areas, and direct resources in an efficient manner. Digital technologies are helpful not just in terms of overall performance, but improving the learning process. These approaches make possible more nuanced feedback for students and improvements in the way that schools function.

It will not be easy to overcome these challenges. Creating data sharing networks necessitates the balancing of student privacy on the one hand with access to data for research purposes on the other. It is vital to maintain the confidentiality of student records, but there needs to be opportunities for researchers and school administrators to mine data for vital trends and helpful interventions. Using privacy arguments to stop research that helps students is counter-productive.

Bringing teachers into the "big data" discussion is crucial because they are the ones, along with parents and students, who will benefit from advances in research and analysis. Projects that let teachers know which pedagogic techniques are most effective or how students vary in their style of learning enable instructors to do a better job. Tailoring education to the individual student is one of the greatest benefits of technology and big data help teachers personalize learning.

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[31] U.S. Department of Education Office of Educational Technology, "Enhancing Teaching and Learning Through Educational Data Mining and Learning Analytics," 2012, p. 36.