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Perspective:

The Promise of Data, Connection and Openness

By Chad Dorsey

We are entering a second grand era of educational technology. Educational technology has grown in scope and complexity, bringing with it new opportunity. Data and analytics hold promise for revolutionizing all aspects of learning. Common platforms permit openness and interoperability to create unexpected combinations. Exciting challenges on the horizon invite us to dive in and explore new, open innovations.

Following upon an incredible first act, beginning in the late 1970's and early 1980's and characterized by countless new ideas and a flurry of initial standalone examples of technology's promise, we are now entering a second era in technology overall and educational technology in particular. Wide consumer adoption has raised the bar for technology's ubiquity and usability across the board. Development patterns, supports and technologies have begun to come together, enabling us to develop new applications with striking ease. This coming era, characterized by convergence, combination and connections, holds intriguing possibilities.

We recently assembled a group of top researchers and software developers to share ideas and ask far-ranging questions about the next generation of technology. Our summit convened around central issues of data, openness and interoperability in the geeky and forward-looking GitHub headquarters in San Francisco. Attendees focused on the grand challenges and opportunities for research and software development in this new era. The results are an exciting instruction book for approaching the future.

Driving toward a new data future

It was clear to everyone gathered that data are poised to redefine learning in the decades to come. What is less clear is how these data can be best used, and by whom. The most obvious users of data in many applications are teachers—a proliferation of dashboards has come onto the scene in recent years, spilling heaps of data into the classroom and, presumably, into teachers' lives. But there is an immense amount we don't yet know about how to use data to help teachers, and this mountain of open questions far overshadows the few things we know.

We certainly know that we can collect data. However, research around how and when to provide that data is in its infancy. Indeed, it is becoming clear that presenting data to teachers creates its own pedagogical challenges. Dashboard designs may subtly or overtly impede teachers from directly attending to students during learning—these are among the pitfalls that await as we experiment with new forms and processes in the classroom.

We also know that simply collecting data is not enough. We know little about what kinds of data are most useful and how to use the data. We need to gauge what learners are doing with the complex and rich tasks assigned in classrooms. Thus, it will be essential to identify actionable data, and to then determine ways to help teachers use these data to enhance learning and to help designers guide curricular design.

But perhaps the primary area of uncharted territory revolves around presenting data about students' learning directly to the students themselves. Students' own data should be made available to them, in a way that can help them better understand their learning. Data should be selected, oriented and presented in such a way as to encourage reflection, spur persistence and build agency. Analytics and data should help education become more individualized, ensure that students are less marginalized and truly place the focus on the learner.

Interoperability and openness

Of course, data can be used in ways that are limited—or unbounded. Rather than piece together portions of code into amazing but sometimes clunky applications, we can instead join multiple applications into coherent combinations. In such cases, the whole is much greater than the sum of its parts. Consumer experience today provides a glimpse of this power, seamlessly connecting personal photo albums to custom-printed books, garage door controllers to mobile phone apps and credit card purchasing

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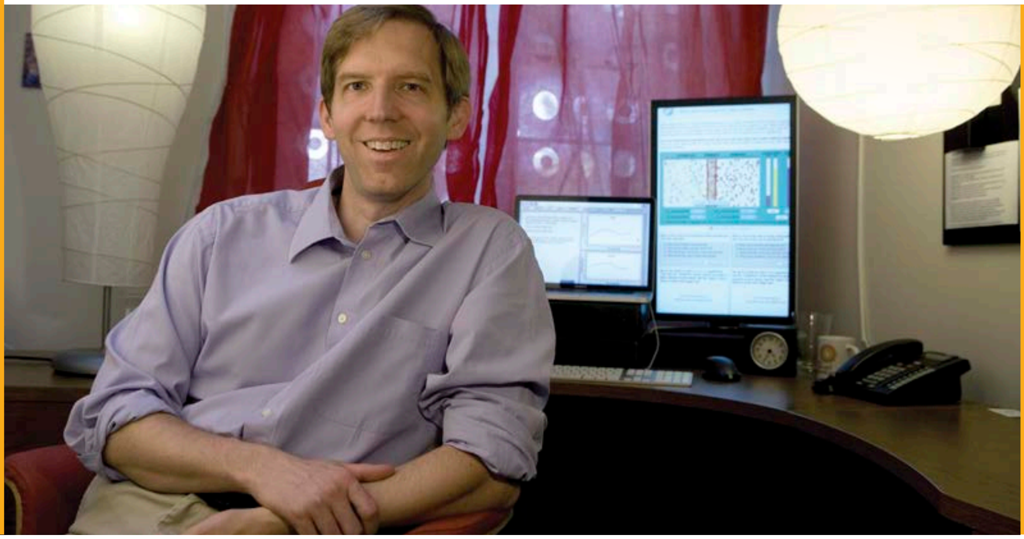
Educational technology needs to be seamless in its ability to piece together unexpected applications from diverse constituent parts, and to build and introspect into the rich learning experiences that result.



data to finance programs. Educational technology needs to be just as seamless in its ability to piece together diverse applications, and to build rich learning experiences.

With the proper interoperability enabled, the possibilities for educational technology begin to look almost unlimited. Such interoperability could provide connections across disciplines within a grade, foster coherence of content across developmental stages, or even provide an invaluable running record of learning across a student's entire educational career, enabling teachers to avoid the age-old problem of starting from square one with every new student each year. Ensuring sufficient levels of interoperability across technologies could unlock new doors across conceptual, cultural and curricular realms.

Such a concept is highly exciting, but immensely complex. And many challenges stand in its way. Interoperability frequently runs counter to the business logic and priorities that drive the creation of today's widely used materials. As schools begin to adopt promising technologies, only to find teachers drowning in a sea of logins and passwords, they are demanding interoperability from vendors and publishers. The need for interoperability of content within school learning management systems is at a similar point. However, ensuring interoperability ultimately means demanding it of developers, a fact that introduces complex intergroup dynamics and can significantly slow uptake of promising possibilities. Groups such as Clever, with its role as a universal hub for solving login and interfacing problems, are beginning to meet some of these needs by providing bridging solutions that smooth the way.

Similar opportunities exist in other places—a universal hub could address many issues with data moving to and from technology-based STEM content, for example. Close coordination among makers of key modeling and simulation technology could help solve a piece of the puzzle, while providing patterns for design and modularity that others could follow. But none of the above will happen easily if the work remains hidden behind walls and guarded by proprietary instincts. At least a basic degree of openness is essential for interoperability to exist, and full openness is what fuels innovation.

What's next?

So how do we figure out ways that data can truly raise teaching and learning to new levels and set the stage for developing the needed critical mass of interoperability? First, we need discussion fed by real examples, and more exchange between software developers and researchers. Our summit was a good start, but it barely scratched the surface. Second, we need real examples as inspiration and blueprint—these are often the only things that truly open people's eyes and make the central needs crystal clear. A set of demonstration projects is essential, showing, for example, how learner data and interoperability could change the experience across all of middle school learning or across multiple STEM disciplines over an integrated high school year.

These are daunting tasks. But we as a community are well prepared. And we have a secret weapon. Because of the blinding speed of technology cycles, we have a unique opportunity, perhaps singular among revolutions. As we enter this second generation of educational technology, we walk forward together with many of those who helped create the original revolution. The resulting foresight, well informed by hindsight, provides clarity for our work. Emboldened by that knowledge, educational technology's second act is ready for all challenges. In the process, the future is not only coming into sharp focus, but beginning to offer us a breathtaking view.

Great Questions Make for Great Science Education

By Amy Pallant and Sarah J. Pryputniewicz

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In science and in education, questions are guideposts. They provide direction, pointing to the unknown, the frontier. The greatest advances in science occur at the interface between the known and the unknown. In pursuit of answers to these questions, scientists have shaped our understanding of the world around us. As knowledge has evolved, so too have the questions. Earlier questions about the Earth focused on how continents moved or on the age of the Earth. Many of today's questions center on issues concerning the planet's capacity to support the growing human population.

Learning to love questions is important. At the frontier, scientists haven't yet discovered the answers; they continue to puzzle through the data, searching for a better understanding of the world. One of the main goals of our High-Adventure Science project is to engage students in the questions themselves, in the same way scientists approach unanswered questions. The idea came from the 125th anniversary edition of the journal *Science* entitled "125 Questions: What don't we know?" Dedicated to describing the most compelling questions then facing scientists, this issue had us hooked, and we hoped similar questions would also engage pre-college science students.

Educators know that sound teaching usually begins with a compelling question. The difference with questions in frontier science is that in the end there won't be definitive answers. In fact, they often lead to more questions. We developed six High-Adventure Science online curriculum lessons with questions such as "What is the future of Earth's

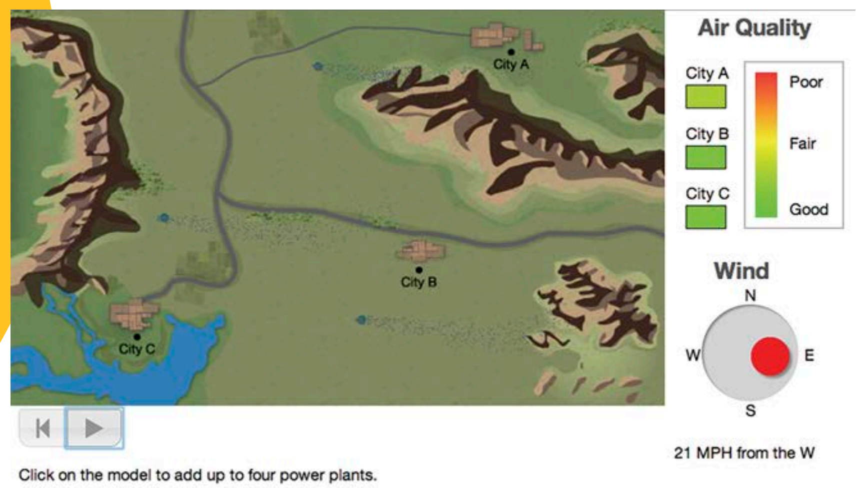

Figure 1. Students explore how location, geography and wind direction impact air quality in different cities in this model.

climate?" and "What are our choices for supplying energy for the future?" to engage students in the broader topics (see sidebar, page 6). An equally important driver behind the curriculum is to help students understand the science of natural systems, so they can begin to recognize and appreciate the different factors that affect the systems. Part of understanding the science lies in determining what is known and what is still unknown, and students are confronted with these questions regularly throughout each lesson.

Start with the science

The High-Adventure Science strategy is to present the science as clearly and objectively as possible, to set the stage for data and models to drive student understanding. Real-world data are complex, so we break down the material into manageable pieces, providing scaffolding for interpretation of the evidence. Approaching the topics this way makes students more likely to be receptive to the information and less likely to get overwhelmed.

Use computational models

Every High-Adventure Science lesson includes a set of increasingly complex dynamic computer models that represent the system under study. Students can change parameters and observe the outputs, which helps them gain insights about each system and its many interacting parts. Because natural systems are complex, we guide students to explore the influence of a selected variable in the presence of other variables on the system, something that is often difficult to do in complex real-world Earth systems (Figure 1).

Analyze data

Even sophisticated models are simplified representations of a system, so students compare model output—and their own conclusions—to real-world data. For example, in the climate lesson, students learn to interpret temperature data derived from ice cores or data collected on the changes in carbon dioxide levels in the atmosphere. As students investigate the data, they discover the relationship between these environmental factors. By combining real-world data with their own experimental data from the climate models, students can look at causality, trends and complexity in the system.

Frontier science means uncertainty

Since frontier questions have no clear-cut answers, the curriculum helps students to address uncertainty and sources of uncertainty as a key scientific practice. The High-Adventure Science project has developed a scientific argumentation item set, which addresses scientific claims and sources of uncertainty. Each argumentation

(continued on p. 6)

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item set includes four prompts that require students to 1) make a scientific claim, 2) explain the claim based on evidence, 3) express their level of certainty with the claim, and 4) describe the sources of certainty. These item sets, used throughout the curricula as well as in pre- and post-tests, encourage students to reflect on evidence from models and real-world data, and evaluate the certainty of scientific claims. We also created and validated an assessment framework that measures students' formulations of uncertainty-infused scientific arguments.

What we have learned

To date, 53 field test teachers have used these activities with over 4,500 students as part of our research. Based on the uncertainty-infused scientific argumentation framework,* we developed scientific argumentation assessment tasks for each lesson, and validated the items with early year pre-test data. Lesson-specific questions were then used as pre- and post-test items. Students have shown significant improvement in their understanding of both science content and scientific argumentation ability as measured on the pre- and post-tests for each lesson.

The future

Over 20,000 users have used the High-Adventure Science lessons, and we expect that number to grow. Two High-Adventure Science curriculum lessons are now available on the National Geographic Education website with more scheduled to go online over the next few months. Our partnership with National Geographic has allowed us to share our resources with their audience and benefit from the expertise of their designers, teacher support frameworks and wealth of related materials.

In addition, thanks to a new grant from the National Science Foundation, students will soon be able to get real-time feedback on their answers to the argumentation prompts. We are currently working with Educational Testing Service (ETS) to develop automatic scoring and feedback associated with the argumentation assessments.

We also hope to create new lessons because Earth science and environmental science are both full of exciting questions. When and where will the next earthquake strike? How big will it be? How does land use affect the atmosphere? The frontier keeps changing, inspiring us as educators to bring these questions to the classroom.

* Lee, H.-S., Liu, O. L., Pallant, A., Roohr, K. C., Pryputniewicz, S., & Buck, Z. (2014). Assessment of uncertainty-infused scientific argumentation. *The Journal of Research in Science Teaching, 51*(5), 581-605.

The High-Adventure Science lessons

Will there be enough fresh water?

Explore the distribution, availability and usage of fresh water on Earth. Students use models to learn how water moves beneath the surface through sediments of varying permeability and porosity. They also use models to test different strategies for preserving freshwater supplies long into the future.

What is the future of Earth's climate?

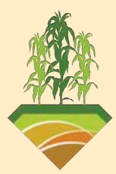
Explore interactions between some of the factors that affect Earth's global temperature. Students examine real-world data on temperature and greenhouse gas concentrations and use models to explore positive and negative feedback loops in Earth's climate system.

Will the air be clean enough to breathe?

Explore the sources and flow of pollutants through the atmosphere. Students use models to run experiments, testing the effects of wind, rain, solar radiation and geography on air quality. Note: This lesson is also available in Spanish.

What are our choices for supplying energy for the future?

Explore the advantages and disadvantages of different energy sources used to generate electricity. A particular focus is given to natural gas extracted from shale formations through hydraulic fracturing.



Can we feed the growing population?

Explore the resources that make up our agricultural system. Students analyze data on land usage and the nutrient needs of crops. They use models to run experiments on the role of slope, climate and tillage practice on soil quality.

Is there life in space?

Explore how scientists are working to find life outside Earth. Students use models to learn how scientists detect extrasolar planets through the "wobble" and transit methods. Students predict which types of planets might harbor life based on their position and atmospheric composition.

LINKS

High-Adventure Science
http://has.concord.org

National Geographic Education
http://education.nationalgeographic.com

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Monday's Lesson:

Graph Literacy: Interpolation

By Carolyn Staudt and Nathan Kimball

Graphs are powerful tools for visualizing data, but too often students are unable to gain insights from them because they never learn the fundamentals of "reading" graphs. The Graph Literacy project is designed to help. We have cataloged the basic steps necessary for interpretation of simple graphs and developed a set of activities to address these steps.

Graph literacy is the ability to identify the important features of a wide variety of graphs and relate those features to the context of the graphs—in other words, to increase student understanding of the meaning of graphs. Graph literacy is emphasized in both the Common Core State Standards for Mathematics and the Next Generation Science Standards. The math standards suggest, for example, that by the eighth grade, students should learn about lines of best fit and what they mean.

Here, we focus on scatter plots and line graphs, both of which are widely used in STEM subjects. In the "Interpolation" activity, middle school students identify and use scales while interpolating between points on a graph. By the end of the activity, students will be able to 1) identify a linear relationship in scatter plot data, 2) find a trend in noisy, experimental data, and 3) use a linear relationship to interpolate points on a graph.

The storyline for the activity is based on crickets and their signature adaptation for communication (Figure 1). Interestingly, the rate of a cricket's chirping is related to the ambient temperature. Students must find a relationship between chirps per minute and temperature.

Finding the trend and slope

Students first find the trend in some noisy data "by eye" and interpolate based on the trend. To define a line they tap two points on the graph, then move the points until they are satisfied they have found the line of best fit (Figure 2). If their line is not within acceptable bounds of the true best-fit line, a sequence of scaffolds guides them to the correct line. (Graph Literacy activities provide hints for all incorrect answers.)

Next, students find the slope. If they need help, the activity breaks down the sequence of steps, showing first the change in y, then the change in x.

Finally, when students have found the mathematical relationship between temperature and chirp rate, they use it to determine the algebraic equation of the line from the graphical trend.

Following the activity students can create a conversion graph for Celsius to Fahrenheit from two known points—the temperatures of freezing and boiling water. Seeing this common conversion represented as a graph removes the mystery around the formulas on which students usually rely, and gives them the confidence to figure out the conversion even if they forget the formulas.

Free Graph Literacy activities

Other Graph Literacy activities include identifying general graph features, recognizing basic functions of graphs, and linking stories and graphs to any common function. Each activity is accompanied by a lesson plan, which details connections to the standards and provides suggestions for classroom use, discussion questions and a related activity. The six activities are available on our website or as a free app for the iPad at the App Store on iTunes.

Figure 1. Activities engage students with graphics and science context.

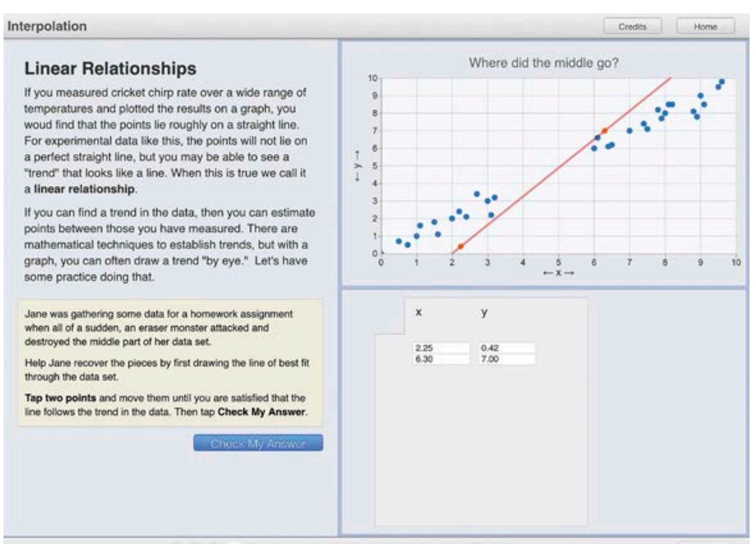

Figure 2. Students can adjust the trend line until they are satisfied they have found a best-fit line.

LINKS

Graph Literacy
http://concord.org/graph-literacy

Interpolation
http://concord.org/graph-literacy-activities

Analytics and Student Learning:

An Example from InquirySpace

By Amy Pallant, Hee-Sun Lee and Nathan Kimball

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In a pioneering new research direction, the InquirySpace project is capturing real-time changes in students' development of new knowledge. As students engage in simulation-supported games their actions are automatically logged. By analyzing the logged data, we are able to trace how student knowledge about a simple mechanical system involving a car on a ramp emerges over time.

The ramp game

We designed a game for high school students to explore relationships among the variables in a car and ramp system (Figure 1). Students discover how friction, mass and starting height affect the distance a car travels after moving down a ramp. The ramp game consists of five challenges that explore different variables. In each challenge, students must land the car in the center of a target by setting the variables correctly.

After each run, the game provides feedback and a score that serve as incentives for students to use the data from the runs presented in the graph or table to succeed more quickly and accurately. If students come close to or hit the center of the target, they move to the next step within the challenge where the size of the target shrinks. The challenges address different relationships within the ramp system (for example, how friction relates to distance the car travels). Later challenges become more difficult.

Knowledge emergence patterns

We embedded the ramp game in our Common Online Data Analysis Platform (CODAP), so students could collect, select and analyze the data generated during the game. All student actions such as changes to variables in the game (e.g., starting height, mass) and scores are logged automatically in the background. To capture moment-by-moment student learning, we analyzed the log data by applying the enhanced version of the Bayesian Knowledge Tracing (BKT) algorithm used in other intelligent tutoring systems.* The BKT analysis of student scores on each challenge identified seven knowledge emergence patterns shown in Figure 2 and Table 1. After discovering these seven patterns, we used screencast analysis to

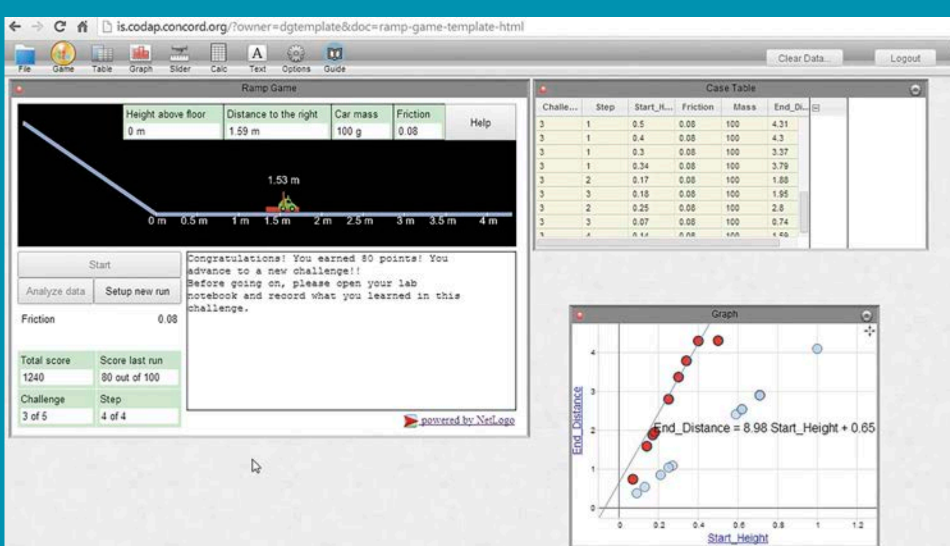

Figure 1. The ramp game embedded in our Common Online Data Analysis Platform (CODAP) software.

investigate how well the categorization based on computationally oriented analyses maps onto student learning of new knowledge related to the ramp system.

Screencast analysis

Students in three 9th grade physics classes, two 12th grade honors physics classes and four 11th/12th grade physics classes from two high schools participated in the research, working in groups of two or three. Two groups per class in one school and three groups per class in the other school used screencast software to record their voices and all onscreen actions throughout the ramp game. We used these screencast videos to investigate whether, when and what type of knowledge emerged in each challenge students completed.

Although the game draws on students' intuitive knowledge of rolling objects on ramps, the ramp game depends critically on students' ability to discern patterns in data, abstract the patterns and apply the patterns to new situations in the game. Students develop content knowledge about the ramp system by examining the data in tables and graphs in CODAP. This knowledge includes 1) how height corresponds to end distance for a given friction, 2) how distance changes when friction changes and what that relationship looks like, and 3) whether mass influences the relationship between height and distance.

The ability of students to use the data—their "data knowledge"—ranged from trial and error to more sophisticated strategies where the groups regularly used the table, a point or line on a graph, or used calculators to plug variables into mathematical equations to solve the challenge. We also noticed that students stuck with a particular format such as table, graph or equation, and improved their data knowledge about the preferred format.

Preliminary results from our screencast analysis have revealed that students need both content and data knowledge to succeed. Having only one type of knowledge did not result in accurate predictions. For example, knowing the positive linear relationship between starting height and distance to target is not enough to land the car on the target every time unless students also know how to accurately interpolate a point from the graph.

Combining qualitative and quantitative analyses

Our research on the ramp game shows that 1) knowledge emergence patterns can be identified from the analytics on students' game scores and 2) these patterns consistently correspond to knowledge emergence events observed in student conversations. By adding the qualitative analysis of the screencasts to quantitative analytics, we were able to uncover more detailed accounts of how knowledge determines student performance on the ramp game.

With real-world validation of student knowledge emergence patterns identified from log data, our next step is to implement these analytics in other instructional games. This is only the beginning, but using real-time data analytics appears to be very promising for automatic diagnostics and real-time scaffolding.

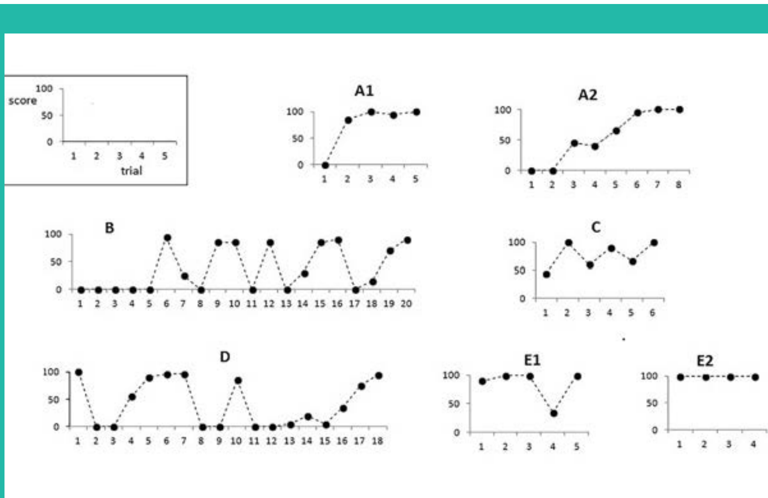

Figure 2. Score patterns were categorized into seven main clusters reflecting knowledge emergence.

	DESCRIPTION
A1	Steady and fast mastery of the challenge where scores start low but then quickly become near perfect.
A2	Steady but slower mastery of the challenge taking significantly more trials to move from low scores to high scores.
B	Slow mastery of the challenge after receiving low scores for some time and then changing to high scores with relatively large fluctuations during the change.
C	Fast mastery of the challenge from medium to high scores with relatively small fluctuations.
D	Re-mastery of the challenge with relatively large score fluctuations.
E1	Near perfect scores, indicating high degree of prior knowledge about the challenge.
E2	Perfect scores, indicating students mastered the knowledge prior to the challenge.

Table 1. Description of the seven knowledge emergence patterns.

* Corbett, A. & Anderson, J. (1995). Knowledge-tracing: Modeling the acquisition of procedural knowledge. *User Modeling and User Adopted Interaction, 4*, 253-278.

LINKS

InquirySpace
http://concord.org/inquiryspace

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Teaching Teamwork in **Electronics**

By Paul Horwitz

For baseball fans the double play is one of the most exciting aspects of the sport. Never mind the home run—the batter pointing toward the centerfield flag, the crack of the bat followed by the arrogant strut to first base—the true aficionado thrills to the exquisite timing and flawless execution required for shortstop and second baseman to deliver the ball to first base milliseconds before the runner arrives. Requiring highly honed individual skills as well as the seemingly effortless coordination that comes only with endless hours of practice, the double play is the epitome of teamwork in a sport that glorifies the term.

Teamwork is increasingly valued in the workplace, too, as telecommunication technology continues to shrink the planet, and the flow of information displaces the exchange of things in the global marketplace. Nowhere is this more true than in the international world of science where advances are rarely made by the proverbial lone genius working in the shadows. And what is true for the laboratory is equally valid for the workplace as a whole. Prospective employers interviewed in 2006, the most recent data available, overwhelmingly rated the ability to collaborate as "very important" for college graduates seeking entry-level jobs.*

But there is a critical mismatch between the value of teamwork in the modern world and its status in an educational setting. The problem arises from the difficulty of teaching students to work together while retaining the ability to evaluate them individually. A high score on a test may reflect the superior performance of a particular student, while the effort of an otherwise exemplary team may be sabotaged by the carelessness of a single member. The difficulty of assessing the performance of each member of a team results in the paradox that the very collaboration that is so prized in the workforce is considered "cheating" when practiced in school.

In response to this dilemma we have embarked on a new project called Teaching Teamwork with Tidewater Community College, CORD and ETS. Funded by the Advanced Technological Education program at the National Science Foundation, the project is aimed at students in electronics classes in technical high schools and two- and four-year colleges. Our goal is to teach students how to work effectively in teams, either face-to-face or remotely over the Internet. Using technology adapted from our SPARKS (Simulations for Performance Assessments that Report on Knowledge and Skills) project, we provide each student with a simulated electronic breadboard and a set of AC and DC components and test equipment. Eventually, the parts list will include digital components and microcontrollers.

Students can link their boards together and use them to build, modify and test realistic simulations of electronic circuits. They work independently on their own piece of the circuit, but they can communicate with their teammates. Local changes made by each student, as they affect the circuit as a whole, may alter measurements made by other students. The computer logs each student's actions as the team works together to design, test and troubleshoot its shared circuit.

We will analyze this data, compare it to classroom observations, questionnaires and other measures, and use it to shed light on the students' collaborative problem-solving skills. We hope to automate this data analysis and use it to generate reports that reliably evaluate the performance of each student as well as that of the team as a whole.

Collaborative tasks

To evaluate a team's performance, group challenges must require collaboration, engage each team member approximately equally, and align to course content and learning goals. In our first collaborative problem-solving task, we present each member of a team of three students with a portion of a simple circuit that consists of a DC voltage source with unknown voltage and internal resistance feeding three variable resistors in series (Figure 1). The students are provided with a schematic of the circuit, but they see only a piece of it on their breadboard. None of them can see the external voltage source, nor measure its voltage and resistance. Instead, each student sees one of the variable resistors and is provided with a voltmeter. The students can change the resistance of their resistor and they can measure the voltage drop across it. Each student is given the challenge of producing a particular value for that voltage drop.

The problem is inherently collaborative because changes made by any of the team members change the voltages measured by the other two, making a "hunt and peck"

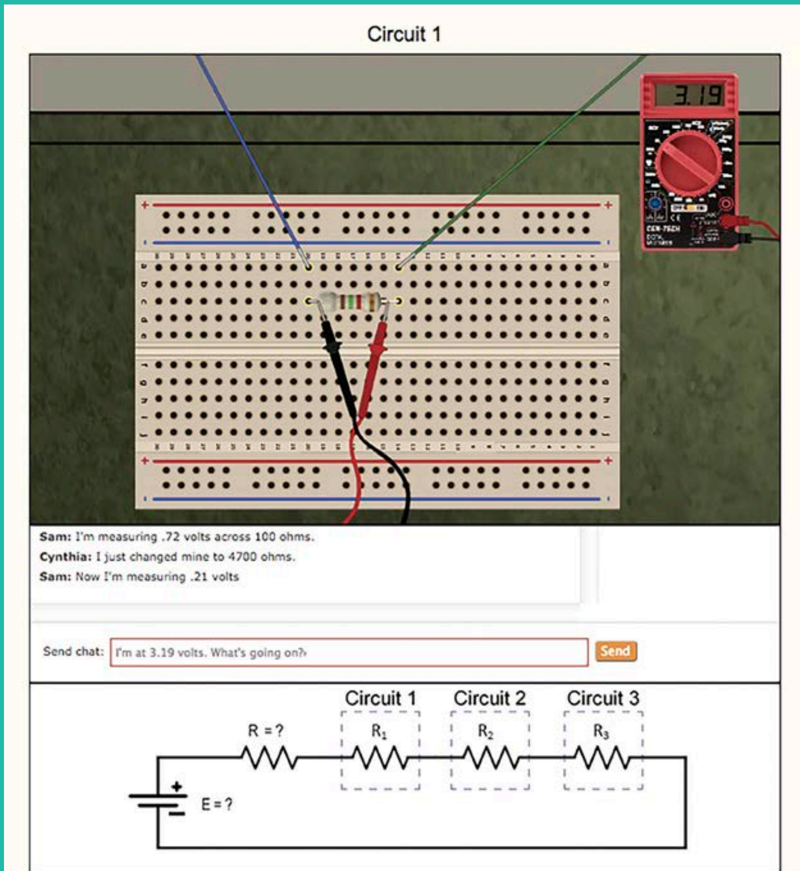

Figure 1. The Teaching Teamwork activity as seen by the student who is in control of the first breadboard. The chat window and schematic are visible to all members of the team; only their breadboards are different.

strategy highly inefficient. If students choose to work on their own, trying to make their voltmeter read the right value by changing their resistor, they quickly find that the actions of the other students frustrate their task. The only strategies that work require the team to coordinate to determine the external voltage and resistance, after which they can work out together the values of their respective resistances that will produce the desired voltage drops.

Preliminary data

We piloted the activity with four three-member teams of students enrolled in a DC circuits course at Tidewater Community College in Virginia Beach, Virginia. All the students were male and ranged in age from early twenties to mid-forties. We explained the problem to them, drew the schematic of the circuit on the blackboard and answered questions. We videotaped the groups and collected log data.

The teams were given approximately one hour to accomplish the task. None succeeded. Instead, each team resorted to the ineffective optimization strategy described above. Each student tried to achieve his individual goal, independent of the others. None of the teams attempted to determine the characteristics of the external voltage source.

Though disappointing overall (given the prior knowledge of the class, the problem should have been easily solvable), this early trial is also quite provocative and begs the question, did the difficulty stem from the students' lack of content knowledge or did it result from their having to work as a team? To find out, we will offer the same problem in two different conditions. Some students will work in teams. Others will work alone. They will be given the same instructions as the teams and provided with a breadboard with three resistances in series, with the same unseen external DC source. Thus, the only difference between the two conditions will be the absence of teamwork in the second. That may make the problem even harder—after all, the solo students will have no one with whom to discuss the problem. Or eliminating the need to collaborate may improve performance on the solo task.

Will the students be able to pull off a double play or will their performance depend on occasional home runs? We can't wait to find out.

* Casner-Lotto, J., & Barrington, L. (2006). *Are they really ready to work? Employers' perspectives on the basic knowledge and applied skills of new entrants to the 21st century U.S. workforce.* The Conference Board, Corporate Voices for Working Families, the Partnership for 21st Century Skills, and the Society for Human Resource Management.

LINKS

Teaching Teamwork
http://concord.org/teaching-teamwork

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From Ship to Shore:

Telepresence Research

By Amy Pallant

In September of 2014, the E/V *Nautilus* set sail to collect data and explore research sites in the Caribbean, including the Kick'em Jenny seamount, the adjacent cold seeps and the Barbados mud volcanoes. On board the ship was the regular cast of characters—scientists, ROV (remotely operated vehicle) pilots, engineers, public communicators and the crew. At the same time, another group of scientists and undergraduate students arrived at the University of Rhode Island's Inner Space Center (ISC), where they were trained by ISC staff on communication and video technology operations to help guide the ocean research.

As part of the National Science Foundation-funded Transforming Remotely Conducted Research through Ethnography, Education and Rapidly Evolving Technologies (TREET) project, this cruise was challenged to use telepresence to transform the way oceanographic research and education is done. The ISC is designed to provide technical support for research expeditions. But coordinating a two-week cruise in which many of the decision makers are directing activities remotely from the ISC was unusual. Another unique aspect of this expedition was the inclusion of undergraduate students. Though they had never been on a research cruise, the students were collecting data to complete their own research projects.

On any cruise, teams work together around the clock, and this project replicated that schedule on board and on land. On board, a constant rotation of watch standers included four people in the command center responsible for directing the ship, the ROV, and the data and video collection. Additionally, there were watch standers at the ISC, including a chief scientist, a research scientist and two undergraduate students per shift. All work was coordinated between the ship and shore groups through satellite video feeds and radio communication technology.

Regardless of location, participants on watch analyzed live video feed from the ROV, developed mapping and data collection plans, and recorded all observations to a science chat area. With two separate locations, the expertise on any given watch was distributed. Sometimes the knowledge base was with a scientist sitting beside the ROV pilot and at other times it was with a scientist or student thousands of miles away at the ISC.

Change in the workflow

Attempting to recreate the shipboard culture on land, watches mirrored the work in the command center aboard the *Nautilus* (though the times were slightly askew with four-hour shifts on ship and six-hour shifts on shore). A daily conference call was set up, in place of a shipboard meeting, for all participants to discuss plans for the dives. Data was collected and sent to shore (when practical, based on what data could be sent via satellite) so participants not on watch could use it for planning purposes. The idea was for everyone to be immersed in the work and schedule of the ship as much as possible. For those on shore, however, this proved harder than expected. Day-to-day life—from other activities at the ISC to calls and emails from respective work and school institutions—was distracting. Although the ISC is equipped with floor-to-ceiling monitors that provided remarkable seafloor views from the ROV and the ship, it was nevertheless difficult to shift to the 24-hour workflow of the ship, even from one of the most technologically advanced remote sites.

Similarly, those on the ship had a hard time grasping what was happening on land, and an even harder time trying to communicate to shore about things that were not visible via the video feed, like the ocean currents that sometimes made it difficult to navigate or the changing weather and sea conditions. But most importantly, it was a new experience to have decisions regarding data collection and mapping choices being made in different places. With such a complex system, there was occasional confusion in communications.

Undergraduate opportunities

One of the project goals was to include undergraduates as authentically as possible in the research community. Typically, if scientists procure money and a berth on a ship, they can bring a student on board. In ocean science that's usually a graduate student familiar with the professor's research interests and with the data collection and analysis tools. But with fewer—and smaller—research ships available, opportunities for students to get involved in fieldwork are limited. This project set out to show that with the use of telepresence, undergraduate students could share in these opportunities, and that their inclusion would be most engaging if they conducted their own research. And it worked! Students were involved in daily cruise maneuvers, and more importantly, in making sure that the data they were interested in was collected.

Three early career scientists—from Harvard University, Michigan State University and the University of Idaho—recruited seven students to participate in the cruise from the ISC. These scientists were responsible for mentoring students as they developed research proposals; helping students get a feel for the ship environment; explaining how things work on the ship; and guiding data collection at the research sites. Students began by conducting and recording observations, and were later able to guide the data collection necessary for their own research. They told the Hercules pilot where to navigate the ROV, helped design mapping routes and made suggestions about what samples to collect at the different sites. While their choices and directions could not always be carried out exactly as planned, both the ship-based and shore-based scientists helped solve issues and mentor the students.

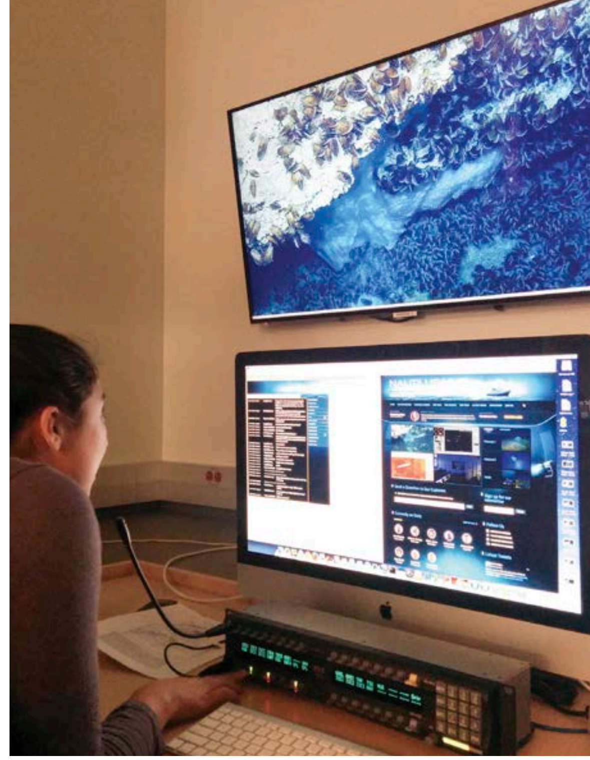
Unexpected outcomes

This telepresence cruise showed that while you can't exactly recreate the experience of being on a ship, it is possible to offer a similar though unique experience from shore. Students and scientists alike at the ISC were engaged in ensuring data and samples were collected for everyone's research needs. One student described his experience: "I came up with my dive plan and was pretty stoked ... was talking back and forth with the scientists about my research and feel good." Another said, "I did some important bubble imaging and photo mosaic-ing today and feel much better about my project." Everyone left the cruise knowing that there were data and samples to begin their analysis.

The overall experience was different, however, depending on location. For example, it was hard for ship scientists to remember that there were scientists and students on shore who were equally invested in the outcome of the cruise. It was hard for shore crew to work overnight and try to sleep during the day, when the world around them was out of sync with their schedule. And it was hard for scientists in general to let students take leadership roles. At the same time, it was amazing to witness the confidence of young students helping to make research decisions, especially given that the research sites were thousands of miles away and visible to them only through video feeds and by the technology of telepresence.

Change is hard. Changing a well-established culture is even harder, but this project revealed what it might take, and highlighted some potential next steps to transform oceanographic research and education.

Underwater photos (above and at right) courtesy of Ocean Exploration Trust.



Students and scientists at the Inner Space Center at the University of Rhode Island. *(Photos courtesy of Zara Mirmalek)*

TREET
http://concord.org/treet

Under the Hood:

Embedding a Simulation in CODAP

By William Finzer and Robert Tinker

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In STEM education it's essential to engage students in undertaking their own projects. But data exploration is often a neglected aspect of student project work. Students must look for patterns in the raw data, identify possible errors and plan further experiments. They also need to add, combine and remove data; transform the data; match datasets to idealized curves and more. The Common Online Data Analysis Platform (CODAP) helps students explore their data. Designed to run in a web browser, CODAP is an easy-to-use, open source data exploration environment.

You can import data into CODAP by dropping a text file into its browser window. Or if you have some JavaScript programming experience you can make a web page simulation that produces data for analysis and investigation in CODAP. Just drop the simulation's URL into CODAP, where it is embedded as an iFrame. Then use CODAP's graphs to explore the data.

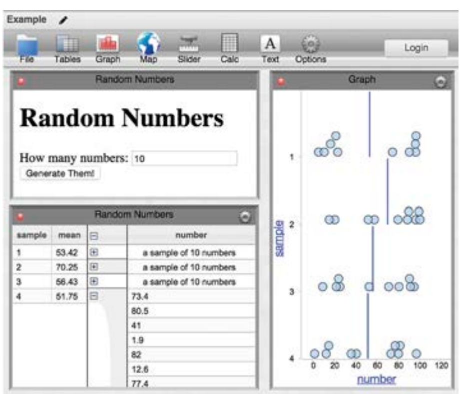

Figure 1. The Random Numbers simulation is embedded in CODAP, having generated four runs of 10 numbers.

Let's look at the data from a random number generator (Figure 1).

1. Go to: bit.ly/1Mie8tO
2. Login as guest.
3. Generate some numbers. Now, make a table and graph, and drag column headers to the graph axes. Play around!
4. Download the HTML for the page: bit.ly/1A5bhxG

As you'll see, most of the file is JavaScript contained between script tags.

In order for an iFrame to communicate with CODAP, the two must establish a connection. This happens in the call to `codapHelper.initSim` where the iFrame tells CODAP its name, dimensions and the structure of the two collections, one for the samples and another for the numbers in each sample. Here's a portion of that code.

```
codapHelper.initSim({
  name: 'Random Numbers',
  dimensions: {width: 300,
height: 200},
  collections: [  // There are
two collections: a parent and a
child
    ...
  ]
});
```

The following code generates one random number and tells CODAP to add it to the data. Try changing the range of numbers or round them to the nearest integer.

```
addOneNumber = function() {
  if( tHowMany > 0) {
    var tRandom = Math.random()
* 100 + 1;
    codapHelper.
createCase('numbers', tRandom,
tID, addOneNumber);
    tHowMany--;
  } else codapHelper.
closeCase('samples', null, tID);
};
```

You might be surprised that there is no loop for generating the numbers. Instead, the last parameter to `codapHelper.createCase` is a reference to `addOneNumber`. This tells the browser that when CODAP is done creating a new case, come back and do it again. This continues until we've generated all the numbers and added them to CODAP's data. Doing things asynchronously like this, the browser redraws continuously so that the points and numbers show up one at a time instead of all at once at the end. It's especially fun to plot values like the mean, which bounces around while the simulation is running.

To learn more about CODAP, join our mailing list at groups.google.com/group/cc-developers or get the code at GitHub: github.com/concord-consortium/codap. A tutorial based on this article appears at: https://github.com/concord-consortium/codap/wiki/Data-Interactive-Tutorial.

LINKS

CODAP
http://concord.org/codap

Innovator Interview:

Jen Goree

jgoree@concord.org

Q. Tell us about the path you've traveled in educational technology.

A. I discovered I really liked programming during a high school math class. In college I enjoyed using code to structure an elegant solution to a problem. I was interested in how technology could solve real problems, especially in education. I worked on educational software back in CD-ROM days and on websites for educational publishers. Then I worked for a large school district near Seattle so I could understand the instructional and administrative sides. After several years, I moved back East and worked for the Massachusetts Department of Education to see what happens at a larger scale. But I really wanted to get back to the instructional use of technology.

Q. What surprised you in the classroom?

A. I was always pleased to see the enthusiasm of individual teachers and their willingness to try new things. It was great to be around people who want to make a difference in the future of their students.

I'm now married to a teacher—he's my focus group of one. I like learning about his challenges of connecting with kids and what works with technology in his classroom.

Q. Were there cases at the state level that were making a difference?

A. The best initiatives were the ones where they brought teachers and principals in from the beginning and asked how it would work best for them on a day-to-day basis. Working with these district partners, we tried to scale up the solution, rather than starting at the state level and pushing an initiative down.

Q. How does your background inform your current work?

A. Having a technical background is helpful with developers even if I'm not getting into every technical detail. I use my background in project management all the time to plan, communicate, look out for risks and keep people involved. And my background with schools, districts and larger scale rollouts helps me understand classroom challenges.

Q. What insights did you gain from your MBA?

A. I wanted a better background in management and leadership. Most people in the part-time program were working, and our conversations were richer when people brought in their workplace experiences. It was also interesting to reflect on how we were using technology in our classes. Simulations were some of the most effective lessons. There's nothing like being fired by a computer!

Q. What was your experience in computer science?

A. There were few women in computer science in college, so we banded together, and the computer science department was very supportive. In Seattle I volunteered with a science and technology conference. Hundreds of middle school girls came to make ice cream using liquid nitrogen or swab their cheeks and make jewelry from their DNA. It was great to see how even a brief exposure can make science come alive.

Q. What do you do outside of work?

A. If I had free time ... (laughs). I have two boys (nine months and three and a half years old). We like going outside as a family. I'm looking forward to the day when the kids will be big enough to do more hiking and camping.

Q. What do you most enjoy at Concord?

A. I really like the spirit of invention, the creativity that people bring to solving problems with technology. They're not looking at what's currently done, but what can be done.

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Data and Analytics Spotlight

One of the Concord Consortium's focus areas involves determining new ways to understand deep student learning of skills and processes such as science practices and engineering design. We've pioneered this research area for many years, incorporating data analytics into open-ended environments, simulations and tools. This past year, new employees and projects are redoubling our efforts.

Dr. Jie Chao recently joined the Concord Consortium as a learning scientist with extensive research experience in technology-enhanced learning environments and STEM education. Dr. Chao completed her doctoral and postdoctoral training in instructional technology and STEM education at the University of Virginia. Her past research experiences range from fine-grained qualitative mental process analysis to large-scale quantitative and longitudinal investigations. She is currently focusing on learning analytics research in open-ended domains such as engineering design and authentic scientific inquiry. With insights in learning sciences and a strong, computationally oriented mindset, she hopes to utilize learning analytics to investigate important questions with unprecedented granularity and generate knowledge for technology and curriculum design that fosters student learning.

Dr. Chao and longtime Concord Consortium senior scientist Charles Xie are applying learning analytics in multiple ways to uncover new insights about essential processes in science and engineering. Dr. Xie is developing novel process analytics and concept map analytics that aim to probe into students' learning of science and engineering concepts and skills through scientific inquiry and engineering design (Figure 1).

Dr. Hee-Sun Lee, another recent addition to our research staff, has spent the past two decades specializing in science education, assessment of curricula and development of technology-enhanced curricula. Dr. Lee received her M.S. in physics and Ph.D. in science education from the University of Michigan, where her thesis focused on science argumentation with middle school students. Since then, she has worked at the University of California at Berkeley, Tufts University and the University of California, Santa Cruz. Dr. Lee examines data from technology-based STEM learning environments.

In the InquirySpace project, Dr. Lee has used streamed logs of student interactions with a novel take on Bayesian Knowledge Tracing, a learning analytics technique for analyzing fine-grained data about student actions. Dr. Lee and project staff have identified and categorized students' learning status in real time as they play a simplified game within our data exploration environment, CODAP. This work has uncovered new domains of understanding that can help guide later automatic assessment or scaffolding of students' learning while they are in process (see "Analytics and Student Learning: An Example from InquirySpace," page 8). Dr. Lee and other Concord Consortium staff are also using data from student actions to run natural language analysis of student arguments, develop real-time automatic feedback, and provide scaffolding supporting students as they explore Earth science models and simulations.

We're pushing into new arenas of data analysis and learning analytics. Through this cutting-edge work, we hope to uncover new opportunities for rich assessment, timely and meaningful student and teacher feedback, and deepened teaching and learning.

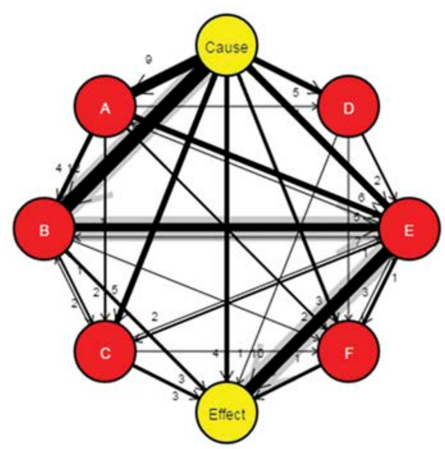

Figure 1. Visual learning analytics for studying student response patterns: aggregating data from a class of students onto a causality digraph with different coding options.

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