Interactive Lab Brings Chemistry to (Virtual) Life

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Studies show that high school students who excel at solving pencil-and-paper chemistry problems from a textbook—and who, therefore, get good grades—often can't make connections between the long string of chemical notations they create and the actual chemical reaction it represents.

For some leading science educators, this situation is analogous to giving students A's in Spanish because they can conjugate a dozen verbs. While they've mastered an important tool of the trade, they may never have actually applied it to speaking or reading the language.

An interactive virtual chemistry laboratory for high school students, developed by The ChemCollective group at Carnegie Mellon University (CMU) and WestEd's Science, Technology, Engineering, & Mathematics (STEM) program, is drawing students into the inquiry process at the heart of chemistry and presenting them with interesting, real-life problems to solve. The ChemVLab+ project, based on a virtual lab developed by CMU, shows promise for improving high school students' understanding of basic chemistry concepts and their appreciation for how chemistry is used to explain puzzling phenomena, develop new materials, and solve problems.

"The ChemVLab+ activities with embedded individualized tutoring give all students access to the benefits of open-ended inquiry in chemistry lab assignments," says Principal Investigator Jodi Davenport, "regardless of their beginning level of proficiency. The technology is also providing teachers detailed performance data they can use to fine-tune instruction. Our preliminary classroom studies suggest students are learning content and inquiry skills and teachers find the reports valuable."

Supporting Inquiry-Based Learning With Detailed Feedback

The original virtual chemistry lab was developed in 2000 by CMU to replace the paper-and-pencil problems that are typically assigned in chemistry class. Its flexible, multimedia learning environment was designed to promote authentic chemistry learning by allowing students to design and carry out experiments. Activities using the virtual lab aimed to help students connect the "math" of chemistry (calculations in traditional problems) with the "science" of chemistry (making predictions, gathering data, drawing conclusions, and generating explanations).

But when CMU pilot tested the modules, student responses indicated that the open-ended environment wasn't working for everyone. Users fell into two distinct groups—those who thrived on the free exploration, and others who were paralyzed with confusion about what to do next.

The new modules developed by CMU and STEM—complete with virtual chemicals, equipment, and tools—use interactive and engaging scenarios to help students make connections between symbolic representations of chemical reactions, molecular models of those reactions, and observable changes in, for example, the color, temperature, or final concentration of chemical compounds.

The activities also contain an intelligent tutoring system that offers hints when a student gets stuck. By responding to user behavior, the system allows students to progress at their own pace, offering them just enough scaffolding to reach the next step in the problem on their own. The goal is to calibrate instruction so that students are working within what psychologist Lev Vygotsky called their "zone of proximal development," that sweet spot of perfectly pitched challenge where students learn best.

The virtual tutor gives graduated feedback, ranging from simple prompting to detailed explanations of how to apply a rule or concept. A log file maintains data on each student's performance, including how many tries were needed to succeed in a learning task and how much help was needed along the way. Teachers can access reports detailing what knowledge or skills were covered, what was retained, and what may need further teaching.

Researchers are in the process of creating eight online laboratory activities. The lab activities address core concepts in high school chemistry, such as conservation of matter, equilibrium, heat flow, and acid-base chemistry. Each activity presents an authentic problem-solving context to motivate the problem solving. For example, in one scenario, students learn about concentration and dilution in the context of preparing drinks of differing concentrations. Using a virtual spectrometer, they determine the concentration of various drinks and prepare a drink of a specified concentration. Other modules focus on using chemical equations and specialized measurement to identify unknown components in a solution; and figuring out whether samples of drinking water meet EPA guidelines.

In each activity, students engage with multiple representations of chemistry from the macroscopic (e.g., concentration of solutions in beakers) to microscopic (e.g., atoms and molecules) and notational (e.g., chemical equations). Students, as an example, analyze chemical reactions by observing changes in solutions, looking at molecular changes as represented by two-dimensional molecular models, and working with chemical equations.

In a pilot study, WestEd's STEM program tested these three virtual lab activities in three California high school classrooms with a total of 69 students. Classroom observations revealed high student engagement and active involvement. What's more, students were able to progress through the exercises with the virtual tutor, either independently or in pairs.

Observers noted that the novelty of the virtual lab tasks allowed some students to break out of their habitual classroom roles. In one instance, a pair of low-performing students was observed engaging in an animated discussion about chemistry. Teachers commented that "students were really involved" and that they "liked using the real settings and tying the chemistry to new contexts."

Performance on post-tests showed significant gains in conceptual understanding of chemistry concepts. An analysis of the log file data revealed that students required less help on subsequent iterations of the same task, and that their patterns of seeking hints showed increasing understanding of the material.

Engaging in Authentic Practice

Although the virtual lab is effective in helping students understand chemistry, its developers did not intend it to replace the chemistry lab experience. Rather, they hoped to enhance the practice piece of the curriculum—the part that would ordinarily consist only of paper-and-pencil calculations—so students could better see the connection between their classroom exercises and the work that chemists do: conducting experiments to explain phenomena, analyzing substances to reveal their chemical makeup, and creating new materials. In short, they want students to recognize that the notations, calculations, and procedures that they learn in chemistry class are simply part of a toolbox that allows chemists to carry out this work.

By taking away some of the vagaries of the lab, where imprecise measurement or uncontrollable variables can prevent results from turning out as planned, the virtual lab allows students to focus on the concepts as they observe the results of their actions. As Davenport explains, "In a real lab, setups are complicated, safety measures must be taken, and errors are often difficult to correct. The virtual lab gives students the ability to quickly design experiments, make mistakes, and try again."

Reframing the Teacher's Role

One of the guiding questions of the project is: can the assessment information gleaned from work in a simulation-based environment allow teachers to make better instructional decisions without increasing their workload? Embedding formative assessments in the virtual lab is one small example of the tremendous potential for technology to enhance instruction by freeing teachers of some of their most time-consuming burdens. The computer provides a detailed analysis of error patterns, allowing teachers to spend less time on grading and more time tailoring instruction according to their own students' needs.

Teachers in the pilot study commented that, because their students were being supported by the virtual tutor, they were able to circulate in the classroom and have valuable interactions with individual students. Log file data on students' use of hints provided a rich trove of information about what they understood and what skills were still missing.

Although the ChemVLab+ activities currently comprise only eight classes out of a year-long high school chemistry course, Davenport and her colleagues foresee the impact extending beyond the virtual lab experience. "Our activities focus on specific topics, but our broader goal is for students to see chemistry as the practice of finding solutions to problems that matter in the world, not just problems in the back of the book. Our activities aim to help teachers and students gain experience with inquiry practices, and actively make connections between mathematical calculations and scientific principles."

"Not only do the activities reinforce important chemistry concepts," she says, "but they provide both teachers and students a new approach to learning chemistry."

For further information about the embedded assessments for The ChemVLab+ project, please visit chemvlab.org or contact Jodi Davenport at 510-402-3274 or jdavenp@WestEd.org.