Molecular Literacy

in the Science Classroom

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Modern science demands molecular literacy. Secondary science educators are increasingly supporting this view even though it requires substantial changes in the way science is taught. The *Science of Atoms and Molecules* (SAM) project has made important contributions to the reordering of the secondary science curriculum by creating materials that help teach students to reason at the molecular level in physics, chemistry, and biology. SAM offers 24 computer-based activities built within *Molecular Workbench* that allow students to explore the atomic basis of important science phenomena.

A remaining question is whether the secondary science sequence of courses is improved by including molecular-level content that builds progressively from one year to the next. Positive results could justify broader implementation of these materials and would provide empirical evidence for additional research and curriculum initiatives. Until recently, however, there was no evidence to assess the success of this substantial shift in science content. The National Science Foundation has funded the Concord Consortium to undertake this research.

Background

The SAM materials were designed to provide the content missing in most "Physics First" curricula. For the physics-chemistry-biology sequence to work best, the basic physics of atoms and molecules needs to be introduced early, so that a fuller understanding of atomic and molecular interactions can be built in the second-year chemistry course. With that strong foundation, students can gain a better understanding of the complex molecular biology interactions in the third-year biology course. The SAM materials provide this content-focused progression.

For example, in a first-year physics course, students learn about heat and temperature, electrostatics, and atomic structure, all of which are critical in understanding intermolecular attractions, a central topic in the following year's chemistry course (e.g., in phase change, solubility, and chemical bonds). In turn, intermolecular attractions are essential in biology for insight into the structure and function of biomolecules such as protein, DNA, lipids, and carbohydrates.

The SAM materials are structured to maximize learning by presenting a progression of relevant molecular concepts over the three-year sequence of courses. All activities are based on guided inquiry, and the same computational engine and molecular visualization tools are used throughout. There is a common format and design for all activities, so students become familiar with the interface and navigation.

In test schools, student gains as measured by pre- and post-tests show that students learned the content. However, do students apply the core concepts from one year to topics in subsequent years? If so, does student understanding grow over the years as a result of multiple exposures to our materials?

Although there are many validated tests in physics, chemistry, and biology, there are no test instruments that focus specifically on molecular concepts only. Therefore, we developed a molecular concept inventory (MCI) for each subject, aligned with the SAM learning goals in each activity, to use as a pre-test and post-test to measure changes in student learning.

The study focused on students in 11th grade biology classes taught by five pilot teachers in Physics First high schools. Each student took a pre-test chemistry MCI and pre-test and post-test biology MCI. In the study, only data for students who completed all three assessments was analyzed (n=141).

The chemistry MCI consists of 22 multiple-choice items and the biology MCI includes 40 multiple-choice items. These items were piloted prior to this research, revised, and tested again to achieve high validity, reliability, and psychometric quality.

We identified how many and which SAM activities students had completed in their prior year chemistry classes. We also collected data on student demographics and attitudes about science.

The Study

This article presents data from part of a larger study. Here, we explore the following research questions:

- Is student exposure to SAM activities in one year correlated with knowledge gains in SAM activities in a subsequent year?
- Is student performance related to the percentage of completed activities in a course?

Results

An examination of the effectiveness of the SAM materials was conducted using pre- and post-tests to assess student content knowledge gains. Dependent means t-tests were conducted to examine whether there was a significant difference between the percent correct scores on the biology MCI pre- and post-tests. The difference between the percent correct on the MCI pre-test and post-test was statistically significant for all 40 items (Table 1).

Statistical analyses were also used to determine whether student performance on the post-test was related to the number of activities completed in biology and chemistry. The results show that the number of biology activities and chemistry activities completed are each significantly and positively related to student scores on the biology MCI post-test (Table 2). Additionally, the results of regression analyses show that for all 40 biology items, the total number of completed biology and chemistry activities is a significant predictor of student post-test scores, after controlling for student pre-test scores.

These results demonstrate statistically significant effects of using the Science of Atoms and Molecules materials. Not only do students who complete more SAM biology activities fare better on the biology MCI post-test, but students who do more SAM *chemistry* activities improve their *biology* MCI scores the following year. These results support our hypothesis that student understanding grows from year to year as a result of multiple exposures to the SAM model-based materials.

Conclusion

These research results are a step closer to demonstrating that a serious treatment of atoms and molecules as a unifying theme across content areas has the potential to improve the science curriculum and student learning across years. As science has been changing to focus on the molecular level, there is an urgent need to revise the secondary science curriculum, teacher training, and professional development. The Science of Atoms and Molecules activities can help teachers realign their classroom tools and strategies in keeping with the most recent and exciting developments in science.

Table 1.		Mean	N	Std. Dev.	Mean Diff.	t	Sig. (2-tailed)
All Items	Pre-test Percent Correct	31.73	141	8.97	- 11.95	-7.54	<.001
	Post-test Percent Correct	43.69	141	20.81			

Table 1. Dependent means t-tests show that the difference between the percent correct on the biology pre- and post-tests is statistically significant (at <.001).

Table 2.	Percent of biology activities completed *		Percent of chemistry activities completed *	
	Pearson Correlation	Sig. (2-tailed)	Pearson Correlation	Sig. (2-tailed)
Pre-test Percent Correct	0.142	.094	0.202	.016
Post-test Percent Correct	0.338	<.001	0.320	<.001

Table 2: Pearson correlations show that the number of completed biology activities and chemistry activities can each be used to predict student learning gains in biology. The value <.001 indicates a statistically significant correlation.

* At least 50% of the activity must be completed for an activity to be considered "complete."

LINKS

Science of Atoms and Molecules
http://concord.org/sam

Molecular Workbench
http://concord.org/mw