

A Cross-Institutional Analysis of the Effect of Web-Assisted Tools on Visualization and Proportional Reasoning in General Chemistry

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Abstract

Visualization and proportional reasoning have been identified as critical skills for understanding fundamental chemical principles. Tools that indicate student learning and the effect of instructional mode as a function of quality of performance in visualization and proportional reasoning are a benefit to chemistry education. Web-delivered assessments for visualization and proportional reasoning within the context of basic stoichiometry were developed and administered to students in universities, community colleges, and high schools in Southern California. An analysis of the assessments including comparison of means across institutions and correlations to the Test of Logical Thinking (TOLT) demonstrates that they are reliable indicators of student performance of visualization and proportional reasoning skills. Analysis of the assessment data reveals that students using Web-delivered instructional tools during instruction in stoichiometry achieve significantly greater gains in visualization and proportional reasoning.

Introduction

Success in beginning chemistry courses often plays a key role in defining a student's academic options. Much work has been carried out to identify those aspects of the chemical sciences that present particular difficulties for students in general chemistry. Herron has recently summarized and synthesized much of this research from the perspective of cognitive science principles in an authoritative volume (Herron, 1996). First, he provides support for the enhanced use of active and cooperative learning in chemistry instruction. Second, he identifies chemical misconceptions that students commonly bring with them into the beginning chemistry courses. Excluding logical misconceptions, Herron has identified two types of misconception important to learning chemistry (Herron, 1996, p187).

1. Many misconceptions are related to concepts that involve proportional relationships: density, equilibrium, mole, acceleration, and rates of various kinds.
2. Many misconceptions are related to theoretical models that require the student to interpret observations in terms of something that cannot be experienced directly: explanations in terms of genetics and evolution, explanations in terms of an atomic model, and explanations in terms of a probabilistic models.

Introductory chemistry courses in particular require students to develop chemical understanding at the molecular level. What is the meaning of the chemical formula? What are the differences between the solid, liquid and gaseous states of a substance? How are the atoms organized and connected in a molecule or polyatomic ion (structure)? How are the atoms organized and connected in solution? What is the meaning of a chemical reaction? How are atoms reorganized during a reaction? Research has shown that deep misconceptions exist about molecular level interpretation of even simple processes such as phase changes at both the college and secondary school level (Ben-Zvi, Eylon, and Silberstein, 1982; Gabel, 1993; Novick and Nussbaum, 1978, 1981).

Conceptualization at the molecular level primarily requires pattern recognition, a correlation between textual (symbolic) and pictorial chemical representations, and mapping of the representations to the concept (Kellman, 1994; Kozma, 1998).

Providing materials and learning tools that specifically address the areas of proportional reasoning and visualization, and that are supportive of activity-based learning thus would appear to be a reasonable strategy for enhancing instruction for beginning chemistry students. A consortium consisting of researchers at California State University Fullerton, University of California Irvine, and several community colleges and high schools in the Orange County region of California have engaged in a project to enhance student learning outcomes in general chemistry through a Web-delivered system of learning tools (<http://www.chem.uci.edu/~rdarasas/index.html>). The project is supported by the United States Department of Education's Fund for the Improvement of Postsecondary Education (FIPSE).

Mastering Chemistry (MCWeb), is a server-based learning and assessment tool for general chemistry developed by Dr. Patrick A. Wegner. The learning application is the core of the server-based learning tool, residing solely on the server (<http://Titanium.fullerton.edu/>). Students and instructors access the learning application using common Web browsers at any time and in any location. A few thousand students from several different institutions can be served simultaneously on a modest server system. It has been used in large university classes at University of Iowa with an enrollment of 500 students, and at the University of California, Irvine, in classes of about 350 students. Each institution obtains data and information pertinent to its courses and students. The learning server presents the software, collects data on student use and

transfers these data to the learning analysis server that provides automatic reports and summaries to both student and instructor. The status of individual student learning and the overall class understanding of complex scientific topics and ideas can be probed. Learning issues that span multiple institutions can be studied with MCWeb.

The instructional design of MCWeb emphasizes proportional reasoning, molecular level conceptualization, and interrelating various representations (graphical, textual and mathematical) of chemical concepts. Consequently, data that illuminates the development of proportional reasoning skills or molecular visualization skills can be tracked at multiple instructional levels for specific types of problems. MCWeb delivers to each student a unique graphic each time the program is used (See Figure 1), but the underlying concept is the same for a particular unit. MCWeb may be used in a learning mode or an assessment mode.

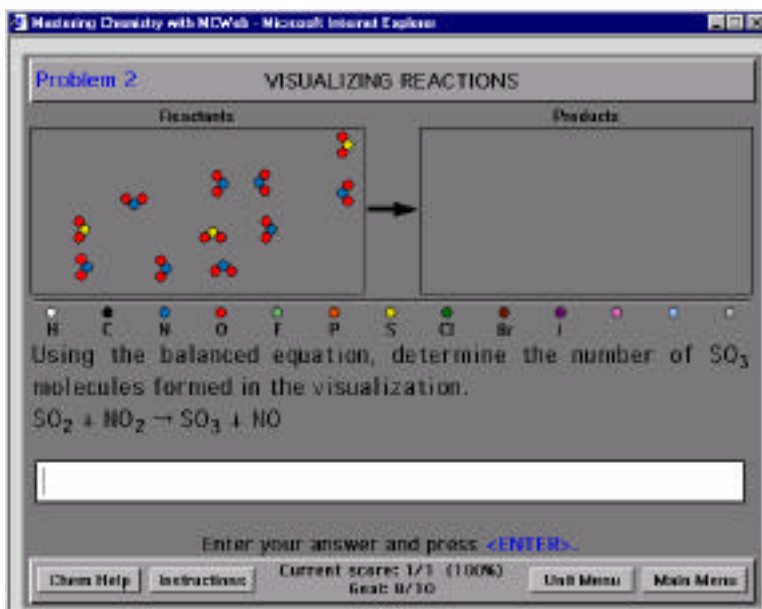


Figure 1. Sample item from MCWeb

In addition to Web-based learning tools, the FIPSE project includes the use of guided instructional activities. Guided instructional activities (GIA) are active-learning pedagogies that incorporate the use of chemical data to assist students in learning key concepts in chemistry. A GIA can be used as a means to introduce concepts that are new to the student or to provide an opportunity for students to apply newly learned chemical principles to problems and processes that are known to be difficult for them to master. GIA's take about 20-30 minutes of class time during which students work either in pairs or in small groups. GIA's do not necessarily require the use of computers.

Study Design

A cross-institutional study was initiated in 1999 to examine student learning outcomes in visualization and proportional reasoning within a stoichiometry context at the university, community college, and high school levels of the first course in general chemistry. The instructors who participated in the study opted for three levels of use of the project tools. Some instructors did not use any of the project tools and served as Level 1 users or control groups,. Level 2 instructors used at least eight MCWeb units, while Level 3 users included eight MCWeb units and eight GIA activities in the curriculum (See Table 1).

	Level 1	Level 2	Level 4
Institution Type	Control	MCWeb	MCWeb + GIA
University	67	450	43
Community College	63	49	19
High School	116	0	98

Table 1 Subjects by Institution and User Level

Results and Discussion

An instrument to assess learning outcomes in visualization and proportional reasoning as they relate to stoichiometry was developed for the project. The On-Line Chemistry Concept Assessment (OCCA) was administered in a pre-/post treatment mode for the first time in Fall 2001. A sample item from OCCA appears in Figure 2. Validation of OCCA was attempted by correlation to three external examinations, the American Chemical Society *First Semester General Chemistry* Test (Fall 97 version), and the Test of Logical Thinking (TOLT) and the Advanced Placement (AP) examination in chemistry. Results were analyzed by type of institution and user level.

What is the chemical formula for the molecules of gas represented in the following box?

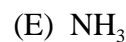
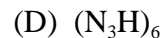
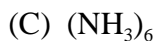
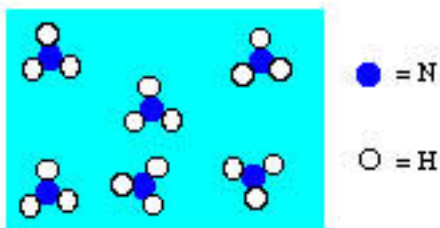


Figure 2 Sample Item from OCCA

University Level

At California State University Fullerton, a comprehensive university, a four-semester study was undertaken to compare student achievement in the first semester chemistry course. One section was a control group in a traditional lecture, recitation section format. The second section was conducted in a studio classroom with lecture and recitation section integrated into three two-hour meetings per week. The instructor used MCWeb units, GIA's, other small group activities with and without computers, and a

curriculum designed about seven recurring threads. A departmental placement examination administered during the first week of the term revealed that the students in both sections had equivalent backgrounds and potential for success in the course. Students were told that both the final examination and the ACS examination would contribute to their course grade. Thus each term of the study, comparable data on the traditional and the guided inquiry group were gathered. Analysis of the ACS Exam results for the pooled data by user level over the four semesters show that the mean score of students in the Level 4 section was significantly higher than the mean score of the pooled control group students ($t = 2.23$, $df = 695$, $p = 0.026$).

Table 2 Summary Data From the CSUF Study					
Comparison of Molecular Science and Traditional General Chemistry Courses					
Placement Test	Spring 98	Fall 98	Spring 99	Fall 99	Average
MCWeb + GIA	13.7	16.1	16.2	17.6	15.9
Traditional Class	15.9	16.9	16.1	17.2	16.5
Common Final	Spring 98	Fall 98	Spring 99	Fall 99	Average
MCWeb + GIA	62.6	61.3	75.6	74.6	68.5
Traditional Class	61.9	60.7	59.6	70.9	63.3
ACS Test Percentile	Spring 98	Fall 98	Spring 99	Fall 99	Average
MCWeb + GIA	51	49	64	65	57.3
Traditional Class	48	59	50	57	53.5

At the University of California Irvine, a research university, the OCCA was administered to two large sections of the first general chemistry course in Fall 2001. Both sections were taught in the large lecture, small group recitation mode. One instructor was a control group, used no project tools and assigned homework from the textbook. The instructor of the other section used MCWeb learning units for homework. There was a significant difference between the mean gain scores on OCCA between the two groups with the MCWeb class having the higher mean score (See Table 3).

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Gain OCCA	Between Groups	2531.8	2	1265.9	43.904	0.00
	Within Groups	25863.599	897	28.833		
	Total	28395.399	899			

Table 3 ANOVA Results UCI OCCA Gain Scores

An additional external comparison of the OCCA instrument was conducted at the university level. The Test of Logical Thinking was administered at the beginning of the academic term. The TOLT score was compared to the pre-test score on OCCA for students at California State University Fullerton and University of California Irvine. There was a significant correlation between OCCA score and TOLT score ($r = 0.16$, $p = 0.05$). A histogram of the TOLT distribution for the two universities is presented in Figure 3.

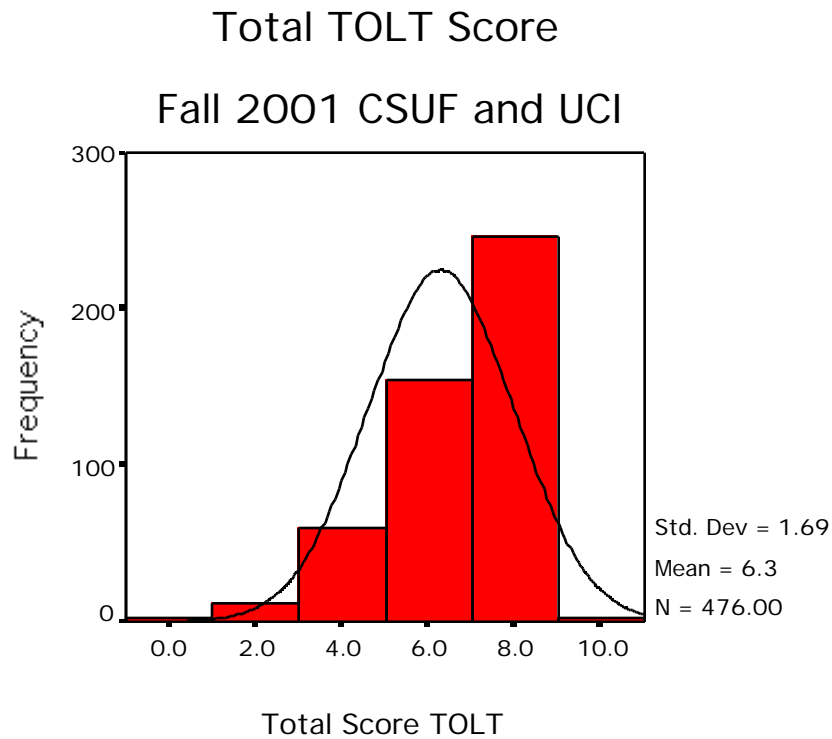


Figure 3 University TOLT Histogram

Community College Level

Community College partners taught the first course in general chemistry in three of the project modes: control, MCWeb, and MCWeb with GIA. The OCCA was administered in the first few weeks of the course and at the end of the term. The mean gain scores by user level were highest for the MCWeb group followed by the MCWeb with GIA group. Both treatment groups had mean scores greater than that of the control group. Analysis of variance and post hoc tests indicate that the differences between groups by mean gain scores is significant.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	348.218	2	174.109		
Within Groups	3554.591	128	27.77	6.27	0.003
Total	3902.809	130			

Table 4 ANOVA Results Community Colleges OCCA Gain Scores

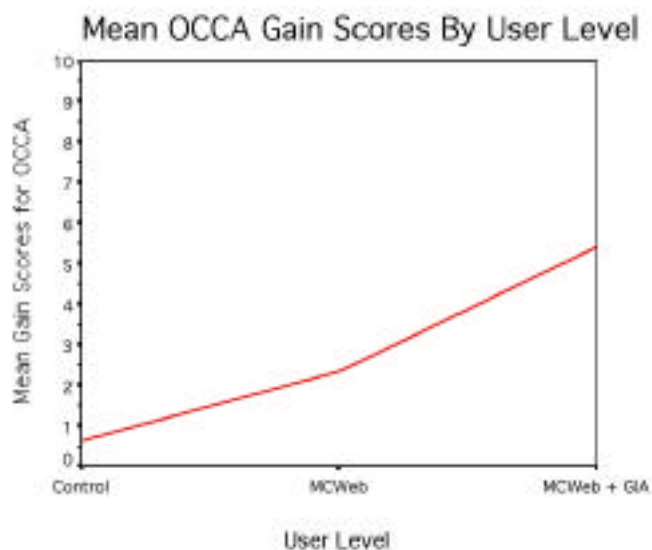


Figure 4 Means Plot for Community College Gain Scores

High School Level

High School partners in the project included instructors of Advanced Placement Chemistry courses as well as college preparatory courses. In the 2001-2002 academic year, treatment was limited to control group and the eight MCWeb units. Linear regression for one high school indicates that MCWeb mean score is a significant predictor of the mean total score for the year-long course. MCWeb accounts for 48% of the total variance in the scores (See Figure 5).

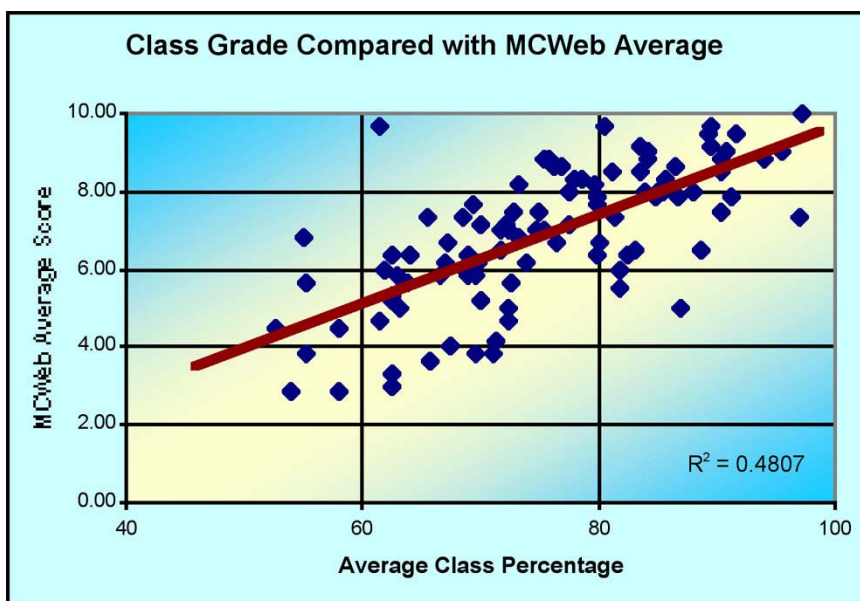


Figure 5 Mean MCWeb Score and Mean Class Percentage Plot for One High School

A comparison of AP exam scores between control and MCWeb treatments at the same high school are presented in Table 4. The high school teacher compared performance of his students who had not used MCWeb tools in two previous years to students who used MCWeb while preparing to take the AP Exam in 2002. The mean AP score for the MCWeb students was greater than that of the pooled mean AP score for those students who did not use MCWeb tools.

	Mean AP Score
MCWeb	3.14
Control Pool	3.00

Findings

The Web-delivered learning tools are making an impact on student learning outcomes across institutional levels. The OCCA is correlated to TOLT and ACS Exam scores. The intent of the OCCA is to provide an instrument with a chemistry context that assesses visualization and proportional reasoning. OCCA gain scores show a significant increase for students who used Web-delivered tools over those who received traditional instruction at the research university, comprehensive university, and community colleges. At the high school level, MCWeb scores are a predictor of success in the course. Mean AP exam scores for students who experienced MCWeb tools were greater than those of students from two prior years who had been taught by the same teacher without them. A second round of data collection is currently in process. This is an important effort to replicate the positive results from the first year of the project and to further validate the OCCA as a viable assessment instrument. While the data presented in this paper indicate that student learning outcomes in visualization and proportional reasoning are positively affected by the use of MCWeb tools, further study is needed to determine the underlying causes for the results.

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