A Web-Based, Calculator-Skills Tutorial and Self-Test for General Chemistry Students

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Abstract: We describe the creation and utilization of a collection of Internet-based materials as supplemental instruction for students enrolled in the first-semester course of a general chemistry sequence. These tutorial and self-assessment materials are intended for asynchronous use as a review of mathematical concepts and skills including functional performance with calculators.

Introduction

Success in solving general chemistry problems and succeeding upon course assessment requires several skills [1]. These include, but are not limited to, the ability to read and comprehend word problems, the application of mathematical expertise including basic algorithms, and higher-order skills like analytical reasoning. If a student is unable to successfully navigate through a series of questions on a particular subject, the sources of difficulty can range from conceptual understanding down to misuse of certain keys or functions on a calculator.

We sought a simple method to assure that students practiced simple algorithmic mathematical skills, including the use of their calculators, before the start of course quizzes and tests. A premise was that the students had achieved sufficient theoretical background in mathematics in high school; a review couched in simple problems that would be completed before any course assessment would help them identify the need for any remediation or, at least, additional practice. The opportunity to offer tutorial materials via the Internet meant that limited and valuable class time would not be used, access to all students was virtually assured, and the materials continued to be available on an as-needed basis. We offer our results and observations for anyone contemplating the use of such a student intervention. Some of the broader issues can likely be generalized to other materials delivered via the Internet, an activity that will continue to become more prevalent.

Development and Initial Offering

Several departmental faculty and staff at UNC-CH outlined the specific goals and objectives for such a tutorial website, including a list of the most common mathematical functions and manipulations used in general chemistry. Grants from the University of North Carolina at Chapel Hill Chancellor's Fund and the Dean of Arts and Sciences provided funds for the implementation of the plan by the Shodor Education Foundation, a nonprofit organization that produces Webware and software for a host of clientele ranging from scientists (i.e., chemistry, physics, environmental sciences) to the blind. The team members from chemistry and from Shodor met on several occasions to refine the goals and address specific implementation plans.

The general chemistry sequence at UNC-CH is comprised of two semesters of lecture (Chem 11 and 21, two semester credit hours each) and two of laboratories (Chem 11L and 21L, one semester credit hour each with the laboratory courses autonomous from the lecture). Only this single general-chemistry sequence is available, and the clientele includes preprofessional and science students including chemistry majors. Majors, however, do not have to be declared until the second year, and the school does not offer any engineering degrees. Approximately 1400 students register for Chem 11 per academic year.

The first website was available for student use in August 1997. The intention was to make the materials accessible at the beginning of the first semester course in general chemistry and to encourage student participation by offering a token reward in the class. The nature of orientation and preregistration at UNC-CH made it difficult to identify those students in the entering class who would enroll in general chemistry until the first day of classes. As a result, we prepared a one-page flyer that was mailed to the home address of every entering first-year student (ca. 3200 people). The message was brief and pointed, "…Don't miss out on the opportunity to be successful in general chemistry…Take the tutorial and self-test and get credit for it in the class..." A URL to the site was provided. A remarkable percentage of the ultimate fall enrollment in Chem 11 completed the tutorial and post-test before the first day of classes (*vide infra*)! The deadline to receive class credit for the

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Table 1. Mathematics and Calculator Topics

Calculator Fundamentals
Business versus scientific calculator
Functions
Scientific notation
Mathematics Fundamentals
Numbers and their properties
Numbers in science
Ratios and proportions
Units, dimensions and conversions
Percents
Simple statistics
Logarithms
Advanced Numerical Methods
Basic matrix math
Linear least squares
Newton's method
Integration techniques

activity was set as October 1 in order to maximize impact on the weekly quizzes and hour exams.

Table 1 contains a list of the mathematics or calculator topics from the first website. Only the calculator and mathematics fundamentals were required; advanced numerical methods were used for a specific set of applications and were optional. The entire set of materials contained ca. 80 screens, not including self-assessment or the post-test. A general idea is presented, a typical problem is solved, and the user practices the acquired skills. Each section is followed by a self-assessment and a score is provided after the quiz is attempted. The complete tutorial is followed by a post-test. Students were identified through a process of self-registration. Thus, a potential user who attempted to complete the post-test was required to fill out an on-screen form that provided sufficient personal information to identify them (including a lecture section if they had already registered). The results of the post-test were recorded but not made available to the user. The scores were subsequently posted after the beginning of classes and at regular intervals after that with an indication of a passing score. Those who were not successful could repeat the tutorial and post-test until they succeeded.

Two versions of the UNC/Shodor site existed until recently although only the current one can be viewed [2].

Student Use and Performance in Year One

One of us taught a large section in the fall of 1997, and data are reported from that cohort. The semester ended with 416 students in that section. The post-test was completed by 76 students (18%) before the first day of classes for the semester and by 285 total students (68%) before the October 1 deadline. (The latter number includes the early group of 76.) The course was a traditional lecture that met three times per week and the course's assessment was comprised of 12 weekly quizzes and a final examination. The students who successfully completed the tutorial post-test (with a passing grade) received credit amounting to 5% of their total course grade as a lump-sum bonus. Those who did not choose to complete the tutorial or who were not successful had their course grade normalized by dividing by 0.95. In this way, the class grades are not skewed by of the 5% bonus.

The topics (column 2) and average scores (columns 3–5) of the twelve quizzes are given in Table 2. All quiz scores are the actual raw scores and are not adjusted.

The average scores are reported for three categories: the complete class (all), those who successfully completed the math tutorial post-test (skills), and those who completed the post-test before the start of classes (early). In addition, the last two columns contain values for the incremental change of the average quiz grades of the skills group compared to the entire class, and the early skills group compared to the entire class, expressed as a fraction of the standard deviation of the entire class. Thus, the change is in units of standard deviations and can be [3, 4] converted to a percentage change. For example, a change of one standard deviation would mean that students that previously performed at the 50% level had been increased to the 84% level ($1\sigma = 34.1\%$, $0.5\sigma = 19.2\%$, $0.3\sigma = 11.8\%$, $0.2\sigma = 7.9$ %, $0.1\sigma = 4.0$ %). The last rows in Table 2 compare the averages for all quizzes and for quizzes 7–12 for the three groups.

Figure 1 contains the quiz grade distribution for the three groups represented in a slightly different way: The group of 76 students who completed the tutorial early (tutorial early, the group who successfully completed the tutorial and post-test after the beginning of class but before October 1 (tutorial completed), and finally those who did not complete it (Did not participate). Note the distribution of student grades in all groups.

Another instructor in the fall of 1997 had a different reward structure and his assessment included hour examinations instead of quizzes. No data were collected from that group. Common hour examinations and finals are not utilized at UNC-CH. Previous evaluations indicate that student distribution among sections of Chem 11 is random within the constraints of class scheduling. As a result, we believe that the data are representative of the entire course enrollment.

The Calculator Site in Subsequent Years

Students filled out an evaluation form on the website after they finished the post-test. We used the feedback from the first year to make changes in the second and subsequent offerings. For example, the students in the first offering welcomed the use of chemical terms and concepts in the context of the mathematics. They felt that even the most basic ideas served as a review for them. They were forced to remember the ideas even though the application might be as trivial as solving a ratio. As a result, a review of basic chemical concepts and ideas was introduced into the site for the second offering in the fall of 1998.

Analysis of the logs showed that students went back and forth among the sample problems, explanations, and quizzes. Students were concerned about the more advanced parts of the course and were interested in a link between tutorial materials and the course content in the event that they sought additional help after the October 1 deadline. From the student responses to the end of tutorial evaluation *after* the initial offering, the vast majority appreciated the "review of chemistry" part of the course, perhaps more than the "how to use my calculator" aspects.

Table 2. Quiz Topics and Quiz Scores for First Offering

	Topics	Average: All[a]	Average: Skills[a]	Average: Early[a]	Skills Change, σ (%)[b]	Early Change, σ (%)[c]
1	unit conversions, significant figures, density	7.52 (±2.41)	7.90 (±2.04)	8.22 (±1.98)	0.16 (6.4%)	0.29 (11%)
2	mass, volume	7.84 (±2.70)	8.39 (±2.14)	8.14 (±2.17)	0.20 (7.9%)	0.11 (4.4%)
3	formulas, grams of atoms	7.53 (±2.45)	7.86 (±2.24)	8.37 (±1.92)	0.13 (5.2%)	0.34 (13%)
4	elemental analysis eqn coefficients	7.18 (±2.75)	7.52 (±2.45)	8.00 (±2.33)	0.12 (4.8%)	0.30 (12%)
5	precipitation eqns empirical formulas elemental analysis	6.45 (±3.54)	6.76 (±3.44)	6.67 (±3.65)	0.09 (3.6%)	0.06 (2.4%)
6	redox limiting reagents	8.24 (±2.47)	8.57 (±2.07)	8.96 (±1.38)	0.13 (5.2%)	0.29 (11%)
7	balanced eqn: mass, solutions	6.03 (±2.93)	6.48 (±2.60)	6.94 (±2.52)	0.15 (6.0%)	0.31 (12%)
8	heat capacity balanced eqns: mass	5.78 (±3.44)	6.28 (±3.27)	6.68 (±3.10)	0.15 (6.0%)	0.26 (10%)
9	ethalpy changes	7.44 (±3.39)	7.93 (±2.95)	8.43 (±2.64)	0.14 (5.6%)	0.29 (11%)
10	enthalpy changes, light, energy	5.37 (±3.31)	5.84 (±3.21)	6.28 (±2.86)	0.14 (5.6%)	0.27 (11%)
11	electron configurations properties	7.44 (±2.72)	7.87 (±2.22)	8.24 (±1.83)	0.16 (6.4%)	0.29 (11%)
12	bond dissociation energy, organic	4.87 (±3.01)	5.32 (±2.96)	5.68 (±2.88)	0.15 (6.0%)	0.27 (11%)
	Quiz 1-12 average[d]	6.89 (±3.05)	7.23 (±2.86)	7.55 (±2.70)	0.13 (5.2%)	0.24 (9.5%)
	Quiz 7-12 average[d]	6.50 (±3.24)	6.90 (±3.01)	7.31 (±2.77)	0.14 (5.6%)	0.27 (11%)

[a]Quiz score (± standard deviation) out of possible 10. All = 416 students, Skills = 285 students, Early = 76 students

[b]Increment of average score of skill completion group relative to all divided by the standard deviation of all in units of standard deviations; the percent increment comes from the area under the normal distribution curve ($1\sigma = 34\%$, $0.5\sigma = 19\%$)

[c]Increment of average score of early skill group relative to all divided by the standard deviation of all in units of standard deviations

[d]Average (± standard deviation) of individual scores.

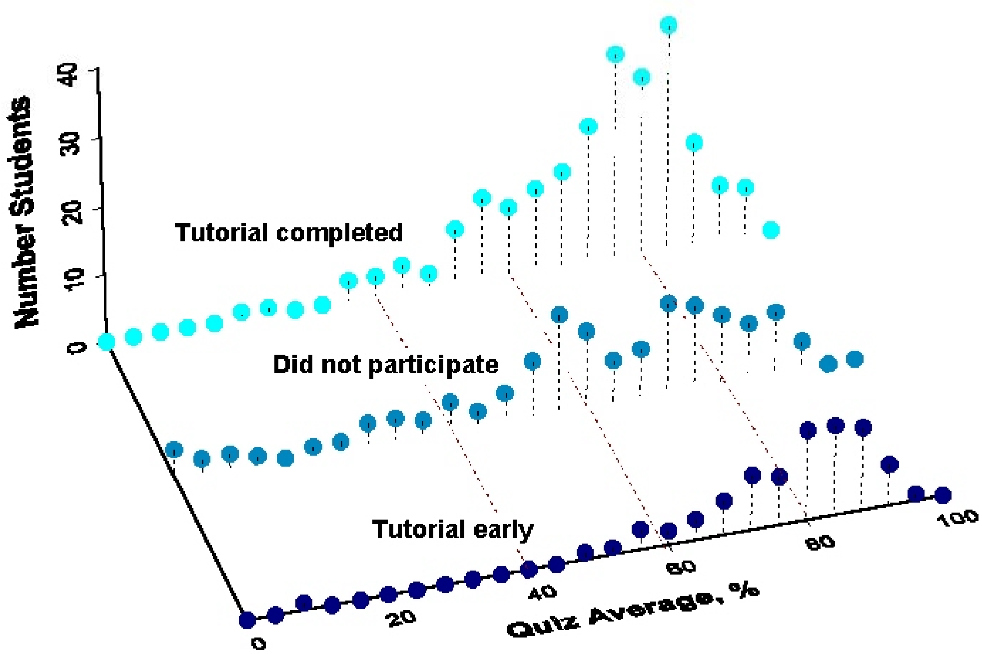

Figure 1. Quiz grade distribution for the three groups.

In addition, the students could request technical support if they had difficulties accessing the materials. Shodor collected and answered these questions; they used this feedback to make adjustments concerning delivery. In the fall of 1997, many of the issues involved very old versions of browsers and the use of ones that were not common. (In spite of some homogenization and the emergence to the forefront of two or three browsers, these issues still arise with amazing frequency today. Instructors who use materials should expect to support student problems arising from the myriad of configurations on personal computers.)

Discussion

The goal of the mathematics and calculator Website was to provide students with an opportunity to review a small but relevant subset of their knowledge and abilities, to help identify any deficiencies with respect to basic math skills, and, thereby, to optimize performance on the course assessments. The student performance data in Table 2 and Figure 1 are intended to help identify those who chose to participate and some basic trends in the outcomes.

In order to meet the first objective, availability, we have to assess whether the potential users made use of the materials given the method established to do so. The portion of the class that ultimately successfully mastered the tutorial and its post-test was 68%. The number of students who attempted the tutorial but were not successful was not monitored. The availability of the materials on the Internet, including all student computer laboratories on campus and several in a chemistry resource center suggests that a majority of the 32% (131 out of 416 students) chose not to participate, rather than being prevented by facilities or circumstances. That is a substantial number until one examines some additional information about that group.

The histogram in Figure 1 suggests that several constituencies may be represented in the group that did not complete the tutorial requirements. The distribution appears bimodal; the students whose average quiz scores exceed the entire class average of 62.5% represent 55 individuals in that group. Although they chose not to participate, it is likely that their choice was made on the premise that they did not need the intervention, a situation supported by their quiz outcomes. Apparently, this group did not respond to the reward because the reward was not substantial enough to warrant their activity. A group of 76 students (i.e., 131 less the 55 above-average students or 18% of the entire class), who did not complete the tutorial, appear to need interventions of some type. In other words, their quizzes indicate that they could use additional help but *they may not have recognized this* or they chose to ignore it.

Analysis of the two groups who *did* complete the skills tutorial and post-test suggests several conclusions. Neither those who completed the material early nor the entire group who completed it represent a narrow range of ability (as evidenced by the quiz scores). In other words, not only the best or worst students are being served by the tutorial, but average students as well. Figure 1 shows that the 76 students in the early group had considerable success with the quizzes. The early group is certainly highly motivated, and it is reasonable to assume that they remained motivated through the course. If that assumption is true, they probably did homework and other activities that are markers for success. Only 15 of these 76 students had a quiz average below the class average.

Table 2 presents quiz averages among the three groups: early, skills, and no skills. Those who completed the math tutorial and post-test scored better on every lecture quiz, although certainly not outside the ranges of the standard deviations. The last two columns show the change in quiz averages as a fractional standard deviation unit or as a percentage increase based on the standard deviations. Note that the percentage increase represents shifts from the 50% level of the class, and the group that participated in the tutorial is more successful in every category. Furthermore, the motivated early group outperforms the other two groups in virtually every quiz. Some of the largest differences (like the maximum value in the last column, 13%) are quite substantial. The smallest changes appear in quizzes 2 and 5. It should be noted, however, that there is not as much difference among the groups in the earlier quizzes; the topics covered in these are likely to be the ones most familiar to students with a good high school background. The complexity and depth to which later topics are covered is likely to increase substantially. This is supported by lower quiz averages in the second half of the course. (See the last two rows of Table 2.)

The data in Table 2 and Figure 1 are likely due to an intractable and complex combination of student ability and motivation. This is substantiated by some quiz topics that are not entirely calculations. In other words, those who completed the skills tutorial or those who completed it early, appear to be more successful even on quizzes where descriptive or conceptual material may be emphasized (e.g., quizzes 5 and 6). We believe that the tutorial materials are successful, but we don't ascribe the trends in Table 2 entirely to that intervention.

Motivation and Optimization of the Reward System

Entering college students are familiar with the rewards and penalties of behaviorism from high school. The student motivation or self-determination theory of Deci, Vallerand, Pelletier, and Ryan [5] describes a continuum from external control to intrinsic motivation. Herron [6] describes it in four levels or stages: (1) external regulation, based entirely on the threat of punishment or temptation of reward; (2) introjected regulation, based on shame and guilt; (3) identified regulation, based on a notion that, like medicine, "its good for me;" and (4) integrated regulation, where the activity is based on one's value system [6]. Based on the promotion of the tutorial in the mass mailings and the announcements about it in class, our intention was to have this tutorial appeal to students above the basic levels of fear and/or greed! It is tempting to assume that the entire group of nonparticipants viewed it as an external regulation; their views of college include ones that liberate them from such activities. We suspect and have evidence that suggests that if the tutorial were a required activity, the level of student resentment would be substantially higher [7].

The role and importance of motivating students appears on a regular basis in college chemistry teaching literature starting over 50 years ago [8]. Several approaches range from the use of gimmicks [9] to curricular changes [10], including applied chemistry or modern research topics [11–14]. Monts and Pickering [15] report on the use of lump-sum bonus points in a laboratory-grading scheme versus incremental points for lecture content assignments within the same group of students [15].

Summary

The mathematics and calculator Website described here was not a high-tech tutorial even though it was Internet-accessible. Although the same material could be printed and mailed to the students, the navigational aspects hide the amount of material to be covered. Technology may provide an attraction that disguises a traditional worksheet. Student-participation differences demonstrate a relationship between motivation and success. Evidence suggests that about half of the group that did not participate in the tutorial should be encouraged to seek more intervention. Additional studies are needed to determine detailed characteristics of the latter group.

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