Designing Interactive Instructional Software: Students as Educators

Kara M. Stamm, Justin T. Fermann, Thomas Whelan, Rachel R. Broudy, Beatrice Botch, and William J. Vining*

Department of Chemistry, University of Massachusetts, Amherst, MA 01003, vining@chem.umass.edu

Abstract: This paper reviews a project conducted as part of a general chemistry course. The primary goal of the assignment was to involve our students in the process of teaching chemistry. Our work is part of STEMTEC, the Science, Technology, Engineering, and Mathematics Teacher Education Collaborative, which has been developed to improve the preparation of preservice teachers, stimulate the interest of undergraduate science and mathematics majors in the teaching profession, and increase the educational effectiveness of science and mathematics courses. The assigned project required students to create an interactive computer module that could be used to educate other students about concepts taught in general chemistry. The paper includes examples of these modules and evaluates this method of instruction. The software programs designed by the students are available for download from the Internet (http://soulcatcher.chem.umass.edu).

Introduction

Two increasingly important goals of the American education system are to improve science and mathematics education and to encourage more young students to pursue teaching careers in these disciplines [1–9]. STEMTEC, the Science, Technology, Engineering, and Mathematics Teacher Education Collaborative, is a five-year project developed to promote reform in the science and mathematics preparation of teachers. Supported by a grant from the National Science Foundation, STEMTEC aims to improve the preparation of preservice teachers, stimulate the interest of undergraduate science and mathematics majors in the teaching profession, and increase the educational effectiveness of science and mathematics courses. (For more information about STEMTEC, see http://k12s.phast.umass.edu/~stemtec/.) As part of this goal, faculty from several colleges and K-12 public schools in western Massachusetts and the University of Massachusetts at Amherst are collaborating to develop and integrate into the curriculum more effective active-learning strategies, such as cooperative learning, investigation-based teaching, educational technology, new assessment techniques, and opportunities to teach [10].

As part of STEMTEC at the University of Massachusetts, we are involved in redesigning and implementing new teaching methods in the sciences [11–15]. What follows is a review of one of the ways that we have changed the curriculum of the general chemistry course for chemistry majors in order to involve its students in the process of teaching chemistry, and at the same time engage them in interactive learning.

The Project

The general chemistry class for majors is already built on interactive learning. Students work in teams, sharing a computer, discussing chemistry problems among themselves, and using the computer to explore solutions. The instructor uses software to lead the students in discovering the chemical relationships and principles that underlie the phenomena observed in the physical world. "Chemland," the guided inquiry software designed for this process, is a set of 45 discovery modules that work through, illustrate, and explore the principles of general chemistry. It is designed for use by both students and instructors, in and out of the classroom.

The students in the class we describe tend to be somewhat more interested in chemistry as a subject than those in our large-enrollment sections. It was certainly clear that particularly strong, interested students enjoyed the challenge of this assignment. Furthermore, the ample time allowed for each stage of the project appeared to support inclusivity for those students who were not as well prepared for the course as a whole.

In order to introduce students to teaching, we created an exercise that asked the students to design a module for Chemland, similar to the ones they had been using in class. In this case, though, they designed a module to aid learning for a topic of their own interest and choosing. In the first semester the exercise required that the students design an educational video or animation, which was later programmed by someone skilled with computer animation. It was found that the time required to program the animations was prohibitive for such a project; therefore, the second-semester students were instructed to create these Chemland-like modules, which required less programming time than the animations.

The project took place as a series of assignments, each of which is described below.

Individual Module Proposals. For the first assignment, each student in the class was required to design his or her own interactive computer education module on any topic covered in general chemistry or on any other (instructor-approved) topic that involved some chemistry. Although they were given the freedom to choose a topic outside of general chemistry, none of the 45 students in the class chose to do so. The students had one week to submit a preliminary design. The assignment given to the students included an example module, prepared by the instructor. The example began with an introduction to the topic of Avogadro's law. The model defined Avogadro's law—the volume of a gas at a given temperature and pressure is proportional to the number of moles of that gas present in

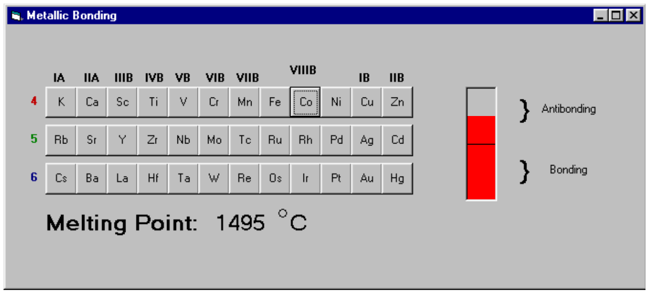

Figure 1. The module that explores metallic bonding.

the sample—and briefly explained the chemistry from which this law is derived. Then, the instructor's example provided a verbal description of the purpose of the module. For instance, the Avogadro's law model explained that the user could choose one of four gases and the number of grams of that gas, and the program would calculate and report the volume of the resulting sample. This description also included a clarification of the variables to be used in the calculations. Finally, a sample diagram of the computer screen layout completed the example. The diagram showed where on the screen input buttons and scroll bars would go, where the title of the exercise was to be placed, and where the answers would be displayed. Basically, the diagram was a picture of what the module would look like to the user. The instructions for the project also contained a list of computer options available to the students in the design of the program.

Group Module Design. After the first drafts of the modules were turned in, the instructor grouped them by similarity of topic and returned them to the students. Students who prepared modules about similar principles then worked together in groups of four for the remainder of the semester. Their first group task was to create one design from their several individual ones. The goal of this section of the assignment was to encourage students to work together to problem-solve, to create an educational tool, and to assess its viability. However, by having each student first prepare his or her own proposal, everyone had to understand the concepts on which the module was based [16]. For those portions of the work conducted during class time, all the students appeared to be actively involved in planning the module, and an effort was made by the instructor to be clear on the expectations of group work.

Each group then worked on their topic to create one module from all the individual drafts. Some groups picked one from among those drafts and other groups wrote entirely new plans based on different pieces of all of the drafts. The students had one week to submit their group module description. This version was reviewed and commented on by the instructor and then revised a final time by the group.

Programming and Revisions. Next, the modules were given to a computer programmer (an upper-level undergraduate student) who programmed the module set. The students were then required to check the program and request any necessary revisions, which the programmer then implemented. In the last step, the instructor performed a final check of the accuracy of the modules.

The order of assignments is intended to have students think individually about how they would teach a subject area and then to reconcile those views with student colleagues. The second phase of the project used group work in order to force students to justify their ideas to one another and to compromise, both with respect to their specific choice of topic and with regard to their choice of pedagogy.

Programming Implementation

We decided that for this project to be useful outside of our immediate group we needed to implement the programming in a way that could reasonably be duplicated by others. For that reason, as well as our limited budget, we chose Microsoft Visual Basic as our programming language. Visual Basic is designed as a rapid development tool for the Windows environment and comes with a suite of easily employed active screen objects. Our work with Visual Basic over the years has showed it to be a highly flexible programming environment requiring a very small learning cycle. It is our experience that an undergraduate student with little programming experience can create useful program modules in a matter of weeks. In the case of this project, the programming was performed by a third year chemistry major with approximately six months programming experience. With the low cost of the programming environment (less than $100) and the ease of finding talented student programmers, this type of project comes within the financial reach of most chemistry departments.

On average, each module completed here took approximately six hours of programming. Part of the ease in programming came from the restrictions placed on the students at the beginning of the project. Certain types of computer interactions, such as buttons and plotting, are relatively easy to program; whereas, others are more programming intensive. Each student was limited to a subset of screen objects that limited the overall complexity involved in programming each module.

Module Examples

The class of 45 students generated 12 modules about general chemistry topics that can now be used to teach other students about principles and concepts of general chemistry. The headings of these modules are:

- Henry's Law
- Reaction Rate
- Gibbs Free Energy
- De Broglie's Equation
- LeChatelier's Principle
- Molarity
- Density of Gases
- Metallic Bonding
- Units of Concentration
- Limiting Reagents and pH
- Calculating pH using the Henderson-Hasselbach Equation
- Orbital Energies in Coordination Complexes

In the module that explores metallic bonding (see Figure 1), for example, the fourth, fifth, and sixth periods of the periodic table are displayed, using the s-block and transition metal columns only. Students can click on any element and the program displays the melting point of the metal and a diagram of a band that is colored in with the correct proportions of bonding and antibonding orbitals. Here students can discover

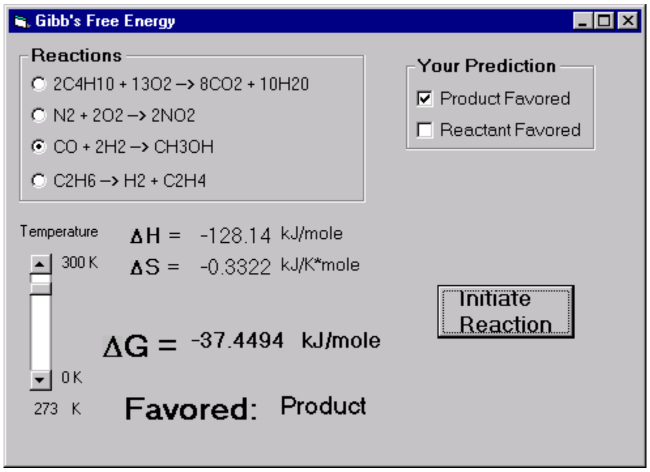

Figure 2. The "Gibbs Free Energy" module.

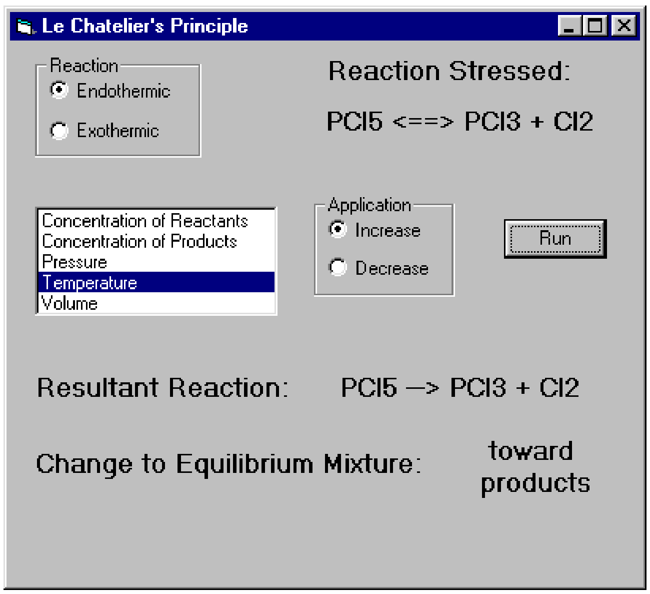

Figure 3. The "LeChatelier's Principle" module.

how melting point trends within the periodic table relate to metallic bonding or band theory.

The module entitled "Gibbs Free Energy" (see Figure 2) allows students to pick one of four reactions and then predict whether the reaction is product- or reactant-favored from the given values of enthalpy and entropy. They can then adjust the temperature and initiate the reaction. The screen then displays the value of Gibbs free energy at that temperature and confirms whether the reaction is product- or reactant-favored. In this module, students can explore the effect of temperature on Gibbs free energy and the relationship between enthalpy, entropy, and the favored direction of a reaction.

A third module called "LeChatelier's Principle" (see Figure 3) allows students to choose either an exothermic or endothermic reaction and then to increase or decrease the concentration of reactants, the concentration of products, pressure, temperature, or volume. They then run the reaction and the program shows how that increase or decrease shifts the equilibrium. In this program students explore and discover the effects that changing certain variables has on an equilibrium and how a reaction will adjust to reestablish equilibrium.

It is apparent that to develop these modules the students first had to develop their own thorough understanding of the relationships and principles addressed by their program module. The students had to be able to locate and then explicitly articulate the relationships and principles relevant to their topic and find a clear and interactive way in which to express these concepts to others. Furthermore, this exercise gave each student the experience of being a teacher, someone who possesses valuable knowledge that can be shared, not just a learner, a depository for someone else's knowledge. We will study if this and other similar projects have any long-term effects on students' interest in teaching. While serving as teachers, students may discover an interest in a teaching career, or more simply, but just as importantly, students may come to value their own wealth of knowledge. Finally, this process helps students understand that learning is an interactive experience, not just the passive reception of information [1, 14, 17].

Evaluation

After the project was completed, students were asked to provide anonymous evaluations of it. Overall, the responses were very favorable; students claimed that they enjoyed the process and through it gained a greater understanding of their specific topic. The most common criticism was that students wanted more involvement in the project. Some wanted more time, some wanted more complex topics, and some wanted to work individually because they felt that in the group process one or two individuals dominated while the rest had very little input into the creation of the module. Some direct quotes from these evaluations follow:

- The STEMTEC project "sparked an interest in teaching chemistry because we were able to pick a topic and design a module that would explain concepts and be used as a teaching tool, something that students aren't usually seen doing."
- "The project was helpful in that it gave me a good understanding of one topic. We had to determine what was so important about our topic and what we would want others to learn about the topic. You have to completely understand a concept yourself before you can teach it to anyone else."
- "This project was great. It was an outstanding experience to learn a new chemistry topic and then devise a module that could help others understand the topic I had just learned."

In our analysis of the end of the semester course evaluations, we found that 92% of the students agreed or strongly agreed that the teaching methods used in this class helped them learn the course material. In addition, 75% agreed or strongly agreed that the course increased their interest in chemistry. Finally, 84% of the students agreed or strongly agreed that they would recommend this course to other students because of the way it was taught.

For a number of reasons, we have not undertaken a long-term controlled study of the effects of this work on student learning. Because each student works on only a single area of chemistry, we do not have any significant hope of increasing overall course performance. Also, because the area of study is chosen by the student (or by students in a small group), any study of increased examination scores will be confused by the variable proximity of the students' choices of topics to the narrow ones chosen by the instructor for examination. In a separate study we are evaluating the effects of the use of previously prepared Chemland discovery modules on students' learning and their general ability to learn by exploration.

The primary goal of this project is to increase the fraction of talented students choosing teaching as a career. The next step in this project is, therefore, to undertake a study that examines how exercises such as the one described in this paper affect students' long-term choices concerning majors and careers. Because our ultimate goal is to inspire interest in the teaching of science, this information will be very helpful in evaluating the success of these kinds of projects and in directing further curriculum development. This long-term analysis will be broad in that it will cover a number of student choices, such as:

- What major does the student choose?
- Does the student enroll in education courses?
- Does the student receive a teaching certificate?
- Does the student become an educator?

The study will also be broad in the sense that it must take into account similar efforts by other instructors at the university. Many students will encounter other courses that include components designed to increase their interest in teaching.

Summary

In this paper we describe a project intended to increase student's interest in teaching. While our early results indicate a positive influence on student's attitudes towards chemistry and teaching chemistry, a long-term study is needed to allow us to observe the effects on ultimate student career choice. It is worth noting that the mode of teaching used in this particular project should not be important. We chose to have students develop interactive computer modules, but the same type of activity could be undertaken by producing educational materials in many other forms, such as web pages, or text-based chapters on real-world applications of chemistry concepts. The benefit of the activity is that it places the student in a situation where they make decisions about teaching chemistry topics. The mode of that teaching is less important than the thought required to decide how to explain the concepts.

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