SMARTTUTOR: A UNIFIED APPROACH FOR ENHANCING SCIENCE EDUCATION*

Keith Harrow
CIS Department
Brooklyn College
theharrows@aol.com

Danny Kopec
CIS Department
Brooklyn College
kopec@sci.brooklyn.cuny.edu

Ron Eckhardt
Biology Department
Brooklyn College
ronalde@brooklyn.cuny.edu

Mark Kobrak
Chemistry Department
Brooklyn College
mkobrak@sci.brooklyn.cuny.edu

Paula Whitlock
CIS Department
Brooklyn College
whitlock@sci.brooklyn.cuny.edu

ABSTRACT:

SmartTutor is an on-line tutoring site created to help students in a number of gateway science courses. The project uses the idea of a concept map, plus collaborative learning and computed-based instruction techniques. SmartTutor provides an alternate path for students who may otherwise be too busy or too intimidated to seek help in the more usual ways. This paper will discuss three specific content areas: introductory computer programming, biology, and chemistry.

INTRODUCTION

SmartTutor is an innovative computer-based learning strategy created at Brooklyn College as an adjunct method for mastering college-level science. The original project[1] created and tested on-line tutorials for a variety of gateway science courses including computer science, biology, chemistry, and most recently, physics. The drop-out rate from science courses in both four-year and two-year colleges has been of great national

concern for many years. On most college campuses, tutoring in all forms is generally accepted as an essential tool for helping at-risk students. Through its Learning Center, Brooklyn College (a part of the City University of New York) has a national reputation in the field of peer tutoring. The Brooklyn College Learning Center has had programs funded by the NSF, the Howard Hughes Medical Institute, and the U.S. Department of Education.

The SmartTutor model builds on this work, using the best that is known about collaborative learning and computer-based instruction to respond to the needs of urban public college students in critical gateway science courses (for majors) and core courses (required for non-majors). The project employs insights from five years of campus research on on-line tutoring to ensure that students have available effective instructional materials to aid their science education. The original SmartTutor project has expanded to a team of faculty from biology, chemistry, physics, computer science, mathematics, psychology, and economics. These faculty members have had considerable experience with summer bridge programs, immersions, and other support programs for non-traditional students. One of the important payoffs of the SmartTutor project is that the faculty members involved have come to better understand many of the causes for student failure, and they have been able to share what they learned with colleagues at Brooklyn College and the academic community in general.

Another innovative part of the SmartTutor program is the use of student peer tutors. Peer tutors through their interaction with students at the Learning Center, know from experience, the kinds of difficulties other students have in trying to learn science. The peer tutors then work with faculty members in the design of our tutoring sites. In addition, we employ a group of advanced students, both undergraduate and graduate, who work on the web design and computer graphics aspects of the project.

SmartTutor has been designed to promote ease of use, including concept maps, animated graphics, exercises and glossaries, content based on careful research into student learning, TutorTips, and answers to frequently asked questions (FAQs). Students who seek help come with varied levels of understanding and varied needs. As they use SmartTutor, these students can follow their own idiosyncratic paths to learning. The SmartTutor project was designed to formulate a model that will support students working at their own initiative and at their own pace to integrate and synthesize scientific knowledge. It combines collaborative learning techniques with on-line tutoring techniques (individualized learning and coaching controlled by the learner). It is intended to provide all students with access to the best possible content and to provide an alternate path for students who may otherwise be too busy or too intimidated to seek help in the more usual ways.

Unlike traditional forms of computer assisted instruction where the learner moves in lockstep through a structured, hierarchically graded sequence of information, SmartTutor is asynchronous, designed for students to go in and out of the website at any point during their learning sequence. The guiding principle behind the development of SmartTutor content is SmartBooks[2,3], an intelligent tutoring component designed by Kopec and colleagues to facilitate exploration of a knowledge base. SmartTutor is based on the assumption that ideas are linked together in meaningful idiosyncratic relationships by the learner, rather than by the teacher or the creator of the site. Concept maps are a basic port of entry for every SmartTutor subject, used to guide the learner toward the

information (s)he is seeking. Concept mapping[4] has proven to be an effective strategy for helping students build a conceptual framework on a particular topic and to elucidate the main features and clarify relationships. Also, the map helps students understand how topics relate to each other more effectively than a linear list of topics. By simply clicking on a topic at any level, students are taken directly to the information offered on that subject. Students can easily access previews of what each topic contains by moving the cursor to the objects on the map.

CIS 1.5 SMARTTUTOR

The first part of the development of SmartTutor[5] was for the gateway computer science course, CIS 1.5 (An Introduction to C Programming). The paradigm we use for this portion of SmartTutor is a student working alone, in need of help. The asynchronous nature of SmartTutor guarantees that instructional support is available to students at any time, from any internet-capable computer. This addresses not only pedagogical needs, but also serves to improve student morale by insuring there is always some recourse for the struggling student. Note that this is particularly important at an urban, commuter school like Brooklyn College, where many students have substantial work and family commitments, and they are unable to get support from peers in the next dorm room.

Designed with these objectives in mind, the CIS 1.5 site allows relatively quick access to any aspect of the language. With only a few keystrokes, a student can see examples of complete C programs using a particular programming feature, work on exercises that explore that feature, or get more information on the topic. (The current implementation supports only multiple choice exercises, but efforts are underway to allow more flexibility in the design of self-assessment tools.)

For example, imagine a student who is having problems with a *for loop*, a relatively simple C control structure. Upon entering the CIS 1.5 site, the student sees a high-level concept map which shows a few main areas -- Fundamentals, Control Structures, Input/Output, Functions, Complex types. The student can quickly click on a few items -- in this case, Control Structures, then For Loops. At that point, the student will have a number of powerful tools available. There will always be at least three choices: Examples, Exercises, and More Info. In addition, each of the example programs can be "played" so the student sees a step-by-step program execution. This is especially useful for our targeted audience, students who are just starting out and have trouble visualizing the execution process.

The choices described above appear for each of roughly 25 areas, including both elementary topics (e.g., Arithmetic Operators, Precedence, and *scanf* for reading) as well as more complex ones (e.g., Function definitions, Arrays, and Structures). On the first page of the CIS 1.5 site, we have additional choices for FAQs (questions that tutors tell us come up repeatedly), information on how to use the compiler, a way to contact us, a survey, etc.

Although much work has already been done, there is much more which can be added to the CIS 1.5 SmartTutor site. We are working to link the site to Codelab, a web-based interactive programming exercise system for introductory computer science classes. Each semester, the existing library of exercises and examples is expanded, and the FAQ list is updated continuously. Outcomes assessment is performed in a number

of ways. Questionnaires are distributed to all CIS 1.5 students three times per semester, after each of the class exams and at the final exam. These questionnaires address the student's perceived need for tutoring help, identify what if any tutoring resources the students actually use, ask about the effectiveness of such resources, and request suggestions for possible improvements to the site. This feedback has been invaluable in our efforts to improve the website[1].

BIOLOGY SMARTTUTOR

Prior to beginning development of the Biology section of SmartTutor, we wanted to identify those topics commonly included in college-level courses that students seem to have the most trouble mastering. Many students choose Biology over other sciences, believing it to be more accessible and more interesting since it deals with living organisms including themselves. Nevertheless, these students have great difficulty moving from learning new terms and word descriptions (even though illustrated) to truly being able to comprehend and integrate concepts at a high level of understanding. Moreover, they often fail to see the implicit relationships between related concepts.

We have asked faculty who teach beginning through advanced Biology courses, and the students taking them, to rate which commonly included concepts are the most difficult to understand and master. In addition, we have had peer tutors in the Brooklyn College Learning Center keep detailed records of the questions students ask and to identify the most common "problem" topics.

What emerged from these studies was that students consistently had difficulty mastering (1) the structure, information content and replication of DNA, (2) cell division including both mitosis and meiosis and (3) how proteins are synthesized in cells by the processes of transcription and translation. Interestingly, when looking at pre-existing Biology websites on the Internet, we frequently found the same topics covered in great detail. We interpret this to mean that others have also found students have difficulty in understanding these particular concepts.

Since SmartTutor is more than simply a course website, we wanted to find ways of presenting in depth the materials which students find difficult. Our site is organized using concept mapping which allows for non-linear access. Students can go directly to the information that they are seeking, rather than being forced to follow a pre-programmed path.

On the site, content pages break the topics into "digestible bites," then link to more detailed and/or related information. Once students understand this organizational format, they can easily find the level of content they are seeking within a cluster of related pages, and they start to develop a sense of how this information fits together within a larger context. It is important to remember that these students have already been given the same information during traditional lectures or distance learning sites, have a textbook, have access to the teaching staff and tutors, online Internet resources, library collections, specialty books of content outlines and summaries, as well as informal student study groups. So the Biology SmartTutor is **not** meant to be the primary means of conveying

[*] http://lc.brooklyn.cuny.edu/smarttutor/index.html

facts and content information, but rather another tool to help the students develop a deeper understanding and ultimate mastery of selected concepts.

We also give the students a chance to check their understanding along the way. At various levels within the content pages, there are questions which have been designed using Artificial Intelligence (AI) strategies. Students are not presented questions in a deterministic fashion, but rather based on the "knowledge level" represented by their answers. In addition, if a wrong answer or partial correct answer is chosen, students are referred to information which helps them understand why their answer was incorrect and helps fill in their knowledge of that sub-topic.

We believe that the Biology SmartTutor has a strong potential to make a major difference in our students' understanding and mastery of hard-to-grasp concepts. Further development will be directed by the results of assessment of the efficacy of our earlier efforts.

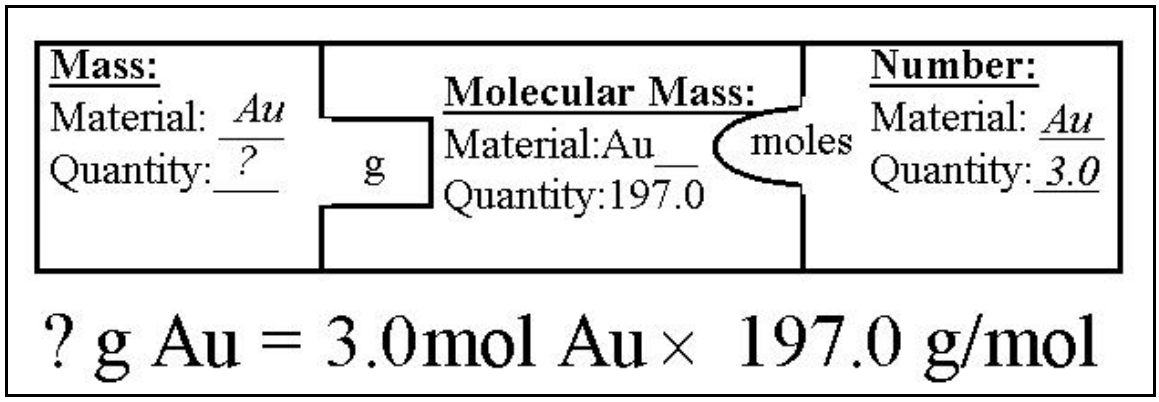
CHEMTILES: AN INTERACTIVE TUTORIAL FOR INTRODUCTORY CHEMISTRY

Introductory chemistry courses are an important part of the required curricula for medicine, engineering, and the sciences. Students are often poorly prepared to study this material at a college level, however, and the development of new teaching strategies and resources is, therefore, invaluable. While at first glance computer-based instruction would appear to be enormously beneficial in this regard, most existing on-line resources for college-level chemical education are not significantly different from those in print. Few, if any, of these sites take real advantage of the interactive quality of the computer medium to engage students in learning at a college level.

We take a unique approach to this problem. Much of the material in introductory chemistry represents the establishment of mathematical relationships between extensive properties (properties dependent on the size of the system, such as mass, volume and mole number) and intensive properties (properties independent of system size, such as mass density, concentration, and molecular mass). These relationships are central to discussions of mass-mole relationships, concentration, stoichiometry, and limiting reagents; these topics represent a substantial fraction of the first semester of college chemistry.

The relationships can be represented by quite simple mathematical expressions, and students often attempt to memorize them individually. Pedagogically, it is important to help students understand that these relationships are not arbitrary, but represent similar expressions based on different physical quantities. Likewise, much recent research in student learning has indicated the importance of appealing to students with different learning styles, including both visual and kinesthetic learning. We propose a simple scheme in which the properties described above are mapped into graphical objects ("tiles"), which can be manipulated by the user. The objects are structured – both visually and within the software – so that they can be arranged on-screen to reproduce their mathematical relationship. A sample of such a construction is shown below. The three tiles – two extensive, one intensive – fit together in a pattern that maps the equation below it. Note that each extensive property has a unique "knob" in its tile, and that the intensive property can accept only those associated with its definition. The user would

begin the problem with a collection of tiles and would have to arrange them to obtain the correct relationship. The student will have to be informed of some additional rules for manipulating tiles (e.g., "flipping" the tile from left to right corresponds to taking an inverse), but these rules are relatively straightforward. The relationship between the graphical structure and the mathematical expression is immediately obvious, encouraging the student to explore it. In fact, the arrangement of tiles represents the creation of a concept map for a given problem, and the creation of concept maps has been proven to be an effective pedagogical tool in the sciences.



This construction offers two major advantages. First, it is visual and kinesthetic, appealing to users who might find it harder to engage with text or lecture presenta-tions. Second, by using such a tile-based approach to study a multitude of physical relationships, the student is forced to recognize the common patterns between the different physical relationships. The result is a methodology that exploits the unique ability of the computer to engage the student both visually and kinesthetically.

Simple constructions of this type are only the beginning. Future extensions of the work will include tiles for unit conversions, and possibly a new form of tile to represent stoichiometric relationships in chemical equations. These problems pose a perennial challenge for introductory students.

Assessment and Summary

As noted above, since the inception of SmartTutor, evaluation and assessment has been built into the project. This assessment has guided the evolution of tutoring aids, and revision is integral to the development process. Assessment helps us predict areas of difficulty so that students will be provided with crucial support, and it tests whether tutorials are successful in promoting student progress. Initially much of the assessment used feedback from a series of informal focus groups made up of students being tutored at the Learning Center. We learned from these initial conferences that students would use a tutoring site if the on-line resource were directly and clearly related to what they were learning in class. Students said they were not willing to surf the web to find help because it was too time consuming. They said the tutoring website had to be easy to use, and it had to contain graphics that would help them visualize concepts.

For the past five years, one of our assessment strategies has focused on in-class questionnaires. Many of the questionnaires have been associated with the introductory course in computer science, a course which consistently loses from 20% to 40% of the

students who enroll. A one-page, voluntary and anonymous instrument was designed to gather data on the following three key issues: (1) How many students were using on-campus tutoring, and how many were using SmartTutor? (2) If students used any tutoring services (SmartTutor or the Learning Center), what were their perceptions of the experience? (3) If they did not use any tutoring services, why was this the case? Here are some examples of the type of information we have been collecting. In over 200 responses in Fall 2004, more than half the students used at least one of these forms of tutoring. More than twice as many students reported using SmartTutor as used the Learning Center. Other comments from students indicate that they found the website to be easy to use, well-organized, and very good at working a student step-by-step through the basic elements of course-required programming skills. The most common criticism voiced by students who used SmartTutor was that it was unable to guide them through many of the deeper and more complex programming problems. In the words of one student after the final exam, "[SmartTutor] was quite helpful in reminding me about the basics of topics. I wished it would go more in depth with problematic areas." This cycle of questionnaires is being used to improve the website, and the next phase will include more complex programming examples. A similar methodology will be used to improve tutorials for all the tutoring aids we develop.

For the past few semesters we have been tracking visits to individual parts of the website. We gather statistics on IP address, the time duration of the visit, the parts of the sites most visited, user patterns (where the users go first, second, third, etc.), the timeline of usage, and other relevant information. We have discovered that peak usage occurs between 6 PM and midnight, with another peak between 2-4 AM, but little or no usage occurs from 8 AM to noon. Usage in the evening is from home, while earlier usage is from college computers. We have discovered that usage increases as the semester moves on, and topic selection moves from fundamentals to more advanced topics. The tracking enables us to gauge student interest and what parts of the site they find most useful. Based on our continuing research including focus groups, questionnaires, and tracking, we have reached some preliminary findings, which we intend to test with larger groups of students and additional courses.

Unlike many tutoring sites, the SmartTutor website is freely available on the Internet and can be accessed either on or off campus. Also unlike most other sites, it is not geared towards a particular section or one instructor's lectures notes. Rather, it is an attempt to provide the student with a wealth of materials that would be of use. The goal is to provide an additional tutoring resource, one which will be especially helpful to students who cannot come see an instructor or go to a more traditional tutor.

ACKNOWLEDGEMENTS

We would like to take this opportunity to acknowledge the support of Dr. Myra Kogen, Director of Brooklyn College's Learning Center during the first five years of this project (2001 – 2005). Without Myra any progress would have been impossible. In addition, we would like to thank Dr. Duncan Dobbelmann, the current Director of the Learning Center, for his continued support. We would also like to acknowledge the NSF for supporting us under CCLI: EMD 023-1185 between 2003 and 2005.

REFERENCES

1. Whitlock, P.A. and Kogen, M., "Creating a Useable Peer-Tutoring Site On-Line*," Journal of Computing in Small Colleges*, **55**, (2002), pp. 143-156.

2. Kopec, D., Brody, M., Shi, C., and Wood, C., "Towards an Intelligent Tutoring System with Application to Sexually Transmitted Diseases" in (Kopec, D. and Thompson, R. B., Eds.) *Artificial Intelligence and Intelligent Tutoring Systems: Knowledge-based systems for learning and teaching*, Ellis Horwood Publishers, Chichester, England, (1992) pp. 129-51.

3. Wood, C.L., "Use of Concept Maps in Micro-computer Based Program Design for an AIDS Knowledge Base," *EDD Thesis*, University of Maine, Orono (1992).

4. Walker, J. and King, P. "Concept Mapping as a Form of Student Assessment and Instruction in the Domain of Bioengineering," *Journal of Engineering Education,* **92**, (2003), pp. 167-179.

5. Kopec, D., Whitlock, P. and Kogen, M. "Enhancing The First Computer Science Course With Peer Tutors, SmartBooks TM and SmartTutors," Chapter in: *Innovations - 2003: World Innovations in Engineering Education and Research* (Eds. W. Aung, M.Hoffmann, et al) January, (2004), pp. 85-94.