Intelligent Tutoring System for CS-I and II Laboratory

Jungsoon Yoo, Chrisila Pettey, Sung Yoo, Judy Hankins, Cen Li, Suk Seo

Computer Science Department
Middle Tennessee State University
Murfreesboro, TN 37132, USA
+1 615 898-2397
csyoojp@mtsu.edu

ABSTRACT

A Web-based adaptive tutoring system which dynamically adapts to each student's needs and gives a student immediate feedback is being developed for our CS-I and CS-II closed laboratories. The system currently contains the question tutor, the program tutor, and the course management components. The tutoring components help students learn programming concepts through hands-on, self-paced exercises. The course management component helps teachers prepare and maintain the lab materials. Experiments have been conducted to evaluate the effectiveness of this new tutoring system and promising preliminary results were obtained.

Categories and Subject Descriptors

K.3.1 [Computer Uses in Education]: Computer-assisted instruction, Computer-managed instruction, Online learning

General Terms

Management, Design, Human Factors.

Keywords

Adaptive tutor, Web-based laboratory, Web Interfaces to Databases, Courseware, Visualization.

1. INTRODUCTION AND RELATED WORK

At Middle Tennessee State University, the Computer Science I (CS-I) and Computer Science II (CS-II) courses are accompanied by laboratories that help students understand programming concepts by providing hands-on programming experience. These labs contain a set of prewritten exercises [7]. During a lab session, a student solves a set of exercises under the supervision of a lab instructor.

Five main problems with this lab setting have been identified. First, the labs are static and do not differentiate students' learning strategies and their wide range of academic backgrounds and abilities. Second, some students do not get enough feedback on their questions during a lab session because only one instructor is available for a class of approximately 30 students. Third, a goal of many students is to finish the lab as quickly as possible, and this causes some of the concepts presented in the lab to be overlooked because the students' attention/thinking process is not stimulated. Finally, assessment and evaluation of student understanding of concepts for the purposes of modifying the labs/altering lesson plans is often avoided due to its time consuming and tedious nature. To provide solutions to the aforementioned problems, an intelligent tutoring system for the CS-I and CS-II closed laboratories has been developed, called AtoL (the Adaptive tutor for online Learning).

A number of Web-based tutoring systems have been developed recently [2, 5, 10, 12, 16]. Although the general goals of these systems are similar, none of the web-based tutoring systems is "adaptive" in the sense that an individualized teaching strategy is applied after a model of the student is captured. In addition, most of the existing Intelligent Tutoring Systems(ITS) have concentrated on figuring out which concepts a student currently understands or misunderstands [1, 3]. Unlike the other tutoring systems, AtoL is designed to provide effective tutoring that is tailored to the needs of individual students. Each exercise is designed to target a specific concept, and AtoL creates a student model that captures a student’s current level of understanding of a concept by automatically grading questions in the exercise. Once the student model is captured, an appropriate teaching strategy can be selected or tailored to maximize the student’s learning.

A graphical progress monitoring tool has been developed for AtoL which is similar to the dashboard concept [6, 11]. The system analyzes student work on each lab and presents the results to the student and the teacher so that the student understanding can be monitored in a structured, systematic way. The monitoring tool can also be used to analyze the design of the labs to ensure that the labs contain an appropriate number of exercises covering all concepts.

In this paper the focus is on the experimental results of using the AtoL system. In the next section, an overview of the system architecture, the student model identifier, the strategy adjustment module, and the monitoring tool are presented. Section 3 discusses some implementation issues for the system. For a more detailed description of the system see [18, 19, 20, 21]. Section 4 describes the experimentation results. Section 5 concludes with the future direction of the current project.
2. SYSTEM DESIGN

The goal of the project is to develop an online tutoring system for the CS-I and CS-II laboratories that dynamically adapts to the needs of each student and provides personalized assistance. Adaptive guidance during problem solving can encourage cognitive processes that stimulate learning and discourage cognitive processes that are counter-productive [8, 17]. In order to accomplish this goal, the system must be able to detect each student’s level of understanding and respond accordingly. It should provide advanced learners with more challenging exercises while giving other students opportunities to go back and review the basic concepts if necessary. The system should help students with understanding programming concepts as well as with learning programming skills. Furthermore, the system needs to provide tools that will facilitate the creation and management of the labs and monitor the progress of the students. It is desirable that the tutor be Web-based so that students who have access to the Internet may be able to do the lab on their own.

The AtoL system is built using client-server architecture. Figure 1 shows the architecture of the system. The server side contains the database of questions, students’ information, and their performances along with software that processes any requests from clients. The client side provides graphical user interfaces for the lab, the tutors and the course management component for teachers. It should be noted that the only software required for the student is an Internet browser. Next, each component of the system is described in more detail.

2.1 The Design of the Tutors

AtoL contains two types of tutors: the question tutor and the program tutor. If the question tutor is initiated, the question manager will draw a question from the question bank. The types of questions include true/false, multiple choice, and short answer. Each question has an associated, pre-assigned difficulty level, a solution, and an explanation of the solution stored with it in the database. Using these, the question manager grades the student’s answers and displays the correct answer along with the explanation for it. It also keeps track of the student’s performance so that an appropriate difficulty level of question can be selected for subsequent questions.

If a student initiates a programming exercise in a lab page, the program manager selects an appropriate exercise from the program bank. The program bank contains a set of programming exercises each of which is accompanied by a solution program, a set of test data files, and a brief explanation for the solution. The program manager displays an incomplete program along with instructions for completing the program. A web-browser based programming environment is developed so that students are able to code, compile, execute, and submit a programming exercise. The program tutor grades the submitted program online and provides feedback. The student may resubmit the program until he/she is satisfied. For each question or program solved by a student, the performance manager monitors and records all the student activities along with related information.

Two new layouts of the labs have been designed. The first layout of the labs differs from the original labs in the following way: each lab is partitioned into several web pages — each page addressing a specific concept. On each web page, tutor button(s) are provided so that a student can initiate a tutoring session (See Figure 2). In the second layout of the labs, the student is provided with a single web page that contains a structured outline of the concepts in the lab. For each concept, there is a link to another page that discusses that concept. Beside the label for each concept there is a tutor button(s) that can be used to initiate a tutoring session (See Figure 3).

2.2 The Design of the Adaptive Component

AtoL uses a two-step semi-supervised learning system for strategy adaptation. In the first step, it is assumed that there are three basic student models, corresponding to three distinct learning patterns: challenge type, regular type, and reinforcement type. The challenge type students learn most by being constantly challenged. They tend to learn from their own mistakes. The reinforcement type students require repeated reinforcement to completely understand a concept. The students in the regular group show both reinforcement and challenge type learning patterns. As a student interacts with the tutor, the student’s behavior is passed to the student model identifier.

The model identifier classifies the student as one of the three basic student models. A well-known decision tree based classification system, C4.5 [13], is used to learn the classification
rules for this task. To aid in the classification, online student lab behaviors collected during spring 2004 were manually analyzed and labeled by teachers. A survey was also designed to collect a student’s learning characteristics. One example of a question in the survey is “Do you learn better by thinking through a complex problem than by drill and practice?” These survey questions were designed to identify the student’s perceived learning style. The student responses to the survey questions and the manually assigned classification labels were used to learn classification rules which in turn are used to identify new student’s learning styles [18].

In the second step, the model, together with a basic teaching strategy for this model, is passed to the strategy adjustment module. It has been observed that students that share the same basic learning model can behave quite differently from lab to lab. Thus, for the strategy adjustment module, a Bayesian Markov Chain Clustering algorithm was developed to cluster the students within each basic group into more refined groups that share similar behavior patterns [15]. The optimal partition size is established by the Bayesian Information Criterion [14]. Using the derived set of Markov chains, a student can be placed in the correct peer group based on their performance after a few questions. This is achieved by computing the likelihood of the student’s initial performance data to the set of Markov chain models. The model that gives the highest probability is the best fit model [18].

The adaptive component revises the basic learning strategy of the student using the recent performance of the student and data collected from previous semesters. The tutor then selects an appropriate problem to present to the student based on the revised, individualized strategy.

2.3 The Design of the Course Management System

To develop the tutoring system, teachers need to create a database of labs, questions for the question tutor, and program exercises for the program tutor. The task of preparing and maintaining the database is an endless process. A web-based authoring system for teachers has been developed so that they can conveniently create and/or update the laboratory material. In addition, a problem generator has been developed that can be used to create a template question which can be used to generate multiple similar questions on demand [20].

AtoL also contains an interface to securely manage accounts of teachers, teaching assistants, and students with different privileges. The system provides statistics on student performance by each student, by each question, and by each program exercise.

2.4 The Design of the Monitoring Tool

In order to monitor the progress of a student or class, it is necessary to associate the exercises that the students work with the concepts they are supposed to learn. Therefore, each question in the system is associated with one or more concepts to be addressed in the question. The concepts covered in each lab are organized into a tree structure where the root of the tree is the subject of the lab, each leaf node represents a specific concept to be learned, and an internal node represents a group of related concepts. Note that the entire course material consists of a collection of trees called a forest. Once the concept base is created, progress monitoring information can be displayed in the user’s web browser using Treeview [4, 9] (see Figure 4).

Our monitoring tool uses colored shapes to represent the status of each node: green circles indicate a high level of performance, yellow triangles for an intermediate level, red squares for a low
level, or grey diamonds to indicate incomplete or unavailable data for the particular node. Each node is also capable of displaying context-sensitive information allowing the user to see the detail values of that node. The system allows teachers and students to find a deficiency by locating the highest level node that shows a non-green color. They can then view the tree at any level by collapsing or expanding nodes into their respective sub-trees. Teachers may also customize the range of scores associated with each color. For example, for an advanced student, a node with less than 80% competency may be considered a problem area and the teacher may want to display that in red.

3. IMPLEMENTATION OF THE SYSTEM
All the software used in the current implementation of the system is 100% open source software. The server runs on a RedHat Linux operating system with Apache web sever. The database uses the MySQL database management system and all the managers are written in the PHP scripting language. On the client side, since the labs are written in HTML with CSS style sheets, any Internet browser can be used to access the online lab manual. Client side scripting is done using JavaScript. Access to the lab is controlled by the Apache authentication system and each student is identified by using a user id and a password. Student identification is maintained by using cookies during each session.

The monitoring tool is written in the Java programming language including elements from both J2SE and J2EE. It has been implemented on an open source Servlet container created by the Apache Software Foundation called Tomcat. All pages are written using Java Server Pages which allows Java code to be embedded inside of HTML to provide dynamic content in a format that is easy to write and maintain. Each access to the tool is passed through an authentication filter which determines the current user’s level of access and, based on this access level, will either allow or deny their request.

4. EXPERIMENTATION AND RESULTS
Given the extensive nature of this project, it was necessary to collect data on several different aspects. We were interested in comparing the learning effectiveness of the two new lab layouts with the old lab layout. In addition, we wanted to know which of the three layouts the students preferred most and how they felt about the different components of the new layout.

There were five labs used for the experimentation. Three new labs (File I/O, Selection, and Loop) were designed with the first new layout and the two new labs (Functions and Arrays) were designed with the second new layout. Eight classes, which were taught by four different teachers, participated in the experiments. Students were divided into two groups in each classroom. Students in the first group were presented with labs using the new lab layout and students in the second group did labs in the old setting. Students in both groups worked on the same subjects in the same room.

4.1 Analysis of Student Learning
In analyzing student learning, only students who completed the lab were considered for improvement comparisons. Each student that completed the lab was given a pretest before the lab and a post-test after the lab for each of the five labs. The differences between the pretest and post-test scores were recorded. An analysis of those results (Table 1) show that post-test scores were significantly improved for both old and new lab settings, which means the labs help students’ understanding of the concepts addressed. It is important to note that improvements in post-test scores are consistently higher for the new lab setting than for the old lab setting for all five lab subjects.

One way ANOVA tests were conducted to determine if there were any significant differences in the post-test grade improvements between the old and new lab settings. Four out of five lab results are statistically significant. That means, students using the new lab environments improved more than students using the old lab. Recall that the first three new labs (File I/O, Selection, and Loop) were designed using the first layout and the last two new labs (Functions and Arrays) were designed using the second layout. While two out of three labs with the first new layout show statistically significant improvement over the improvements using the old lab setting, both labs with the second layout significantly outperform the old lab setting. The lack of significance for the first lab may be due to the students’ lack of familiarity with the new lab environment.

It was also observed that the lab completion rates in new lab settings was consistently higher than the completion rate in the old lab setting as shown in Table 2. We speculate that immediate feedback from the system encourages student to continue work on the lab, while students in the old lab setting have to wait for their grade to return. Another possible explanation may be that the adaptive nature of the Atol system stimulates the student learning.

By analyzing the experimental results, it was also found that the course management system was very useful in improving the

<table>
<thead>
<tr>
<th>Table 1. Improvement comparisons in post-test scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>File I/O</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Selection</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Loop</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Functions</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Arrays</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Lab completion rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>New</td>
</tr>
<tr>
<td>Old</td>
</tr>
</tbody>
</table>
teaching quality and the database contents. For instance, discrepancies were found between the difficulty levels assigned by the teachers and the difficulty levels determined by student experience. For example, a loop question in the question bank had a medium level difficulty assigned by a teacher. However, our experimentation results show that only one out of six students solved the problem correctly. Thus, the level of difficulty of the question had to be increased. A teacher can also use this information in class to reinforce the concepts represented in the questions.

### Table 3. The survey result for the layout 2

<table>
<thead>
<tr>
<th>Question</th>
<th>Agree (4 or 5)</th>
<th>Disagree (1 or 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solving similar questions multiple times</td>
<td>78%</td>
<td>9%</td>
</tr>
<tr>
<td>helped you understand the concept</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I like solving the similar questions multiple times</td>
<td>66%</td>
<td>14%</td>
</tr>
<tr>
<td>Displaying the concepts in a hierarchical</td>
<td>66%</td>
<td>9%</td>
</tr>
<tr>
<td>structure helped you understand the overall picture of the material.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Displaying your progress in a tree view with green/yellow/red/gray color nodes helped you monitor your understanding.</td>
<td>64%</td>
<td>17%</td>
</tr>
</tbody>
</table>

#### 4.2 Analysis of Student/Teacher Satisfaction

Another important aspect of the evaluation involves measuring the level of user satisfaction on each of the three types of labs and the different components of the new labs. Three sets of surveys were designed in which students communicated their opinion of the different lab settings. The first survey was designed to test student satisfaction of the old lab setting. It was administered only to students who did labs in the old lab setting. The other surveys were designed to test user satisfaction on the two new layouts as well as the overall effectiveness and efficiency of AtoL. The surveys were conducted after students finished nine labs. Group one students did the first four labs in the old lab setting and the next five labs in two new lab settings. Since group one students had the chance to use the old lab settings they could compare all three settings. Group two students worked all nine labs using the old lab setting.

It appears that the majority of students in both lab groups agreed that the labs were helpful in understanding the concepts better. The level of satisfaction, however, was much higher in the new lab setting: 77% of the students using the new lab design marked either 4 or 5 on a 1 to 5 Likert-scale whereas 57% of the students who used the old lab design responded the lab was very helpful. In addition, 74% of the students in group one agreed that the new style labs were better than old style labs. It appeared that immediate feedback on exercises, online grading, and the online submission process were preferred by most students and they felt that these features aided their learning progress more effectively.

We also asked the students in group one to rank the three lab layouts, the second new layout was ranked first, the first new layout as second, and the old layout was ranked last.

With regards to the second layout (see Table 3), 78% agreed with “solving similar questions multiple times helped understand the concepts.” The survey also shows that 66% of the students think “a hierarchical structure helped them understand the overall picture of the material.”

With regards to the performance monitoring tool, 85% of the students in the summer 2005 classes agreed that the tool was helpful in determining where their knowledge was lacking. In fall 2005, 64% of the students agreed that the tool was helpful. While the numbers in summer were much higher than the fall, we are encouraged by the large percentage of the students who found it helpful in the fall. The summer students were required to use the tool, but the fall students were left to discover the tool on their own.

Teachers were also asked to use the tool and polled for their opinions. All the teachers found the system to be very useful. Some of the teachers’ comments included that the new lab helped them: focus on specific topics by collapsing the tree, determine concepts that needed more class discussion, determine inappropriate difficulty levels of existing questions, determine where more questions were needed in the lab, and be more flexible in assigning the lower bounds on colors for honors classes as opposed to regular classes.

### 5. CONCLUSIONS AND FUTURE WORK

An adaptive tutoring system for CS-I and CS-II closed labs has been developed. The system is Web-based so that teachers and students can access the lab with an Internet browser. The system contains the question tutor, the program tutor and the course management system. The question tutor is designed to help a student learn a concept by solving a series of questions. It adapts to the individual student by automatically grading questions and learning the student’s behavior. The program tutor is designed to help a student learn programming skills as well as the corresponding concepts. It provides a programming environment in which a student can concentrate on specific programming skill. Using a student’s results from the question and program tutors, AtoL employs a two-step semi-supervised learning system for strategy adaptation. First, a classification algorithm determines the basic learning type of a student. Then models learned from a Markov chain clustering algorithm are used to predict the most closely fitting behavioral model and to refine the teaching strategy.

The course management system provides tools for teachers to create and maintain the labs. By providing a Web-based course management system, any teachers who have access to the course management system can collaborate on developing lab materials.

The experiments show that the use of the tutors provides a statistically significant improvement in understanding of concepts. The student surveys also showed that students preferred AtoL because it provided immediate feedback, online grading, and an online submission. In addition to the student surveys, the professor surveys showed that they found AtoL very useful. The hierarchical nature of the system helped them determine course material that needed more discussion or lab
material that needed more questions. It was flexible enough to meet the needs of a regular Computer Science class or honors Computer Science class.

This research is continuing in two different directions. First, while we are very encouraged by the system’s ability to classify students into the appropriate group, we are now concentrating on evaluating the effectiveness of AtoL’s adaptive teaching strategy. We also have plans to use the tool as the teacher’s command console for a PDA-based in-class application that allows students to receive and answer questions on PDA’s given to them for use during class-time. The tool will be used to push questions to the student’s PDA’s and to view the results of the questions. Extensibility is one of the best features of AtoL and one of the many reasons this project has been a success.

6. ACKNOWLEDGMENTS
This research was partially supported by the NSF grant DUE-0311367 and the FRCAC grant at MTSU.

7. REFERENCES