1 Student Learning Goals

The Department’s overarching goal is to increase students’ proficiency in computational thinking and practice in a liberal arts context, which includes skills such as algorithmic problem solving, abstraction, top-down design, analysis and testing. We focused on our introductory courses (21 and 21B), where the aim is to teach students algorithmic problem solving by drawing on concepts fundamental to computer science.

2 Student Learning Objectives

A student completing our introductory courses should be able to:

- Given a problem described in English, design a clear, concise, and correct pseudocode algorithm to solve it.
- Use the top-down design technique to sub-divide a large problem into reasonably sized sub-problems.
- Given a pseudocode algorithm, successfully implement it in a high-level programming language.

The last objective is easily assessed through traditional methods such as quizzes and lab assignments because implemented code can be executed and tested for correctness. However, the objectives most closely linked to our overall aim of teaching computational thinking—developing algorithms and using top-down design—are harder to assess through standard methods. Our assessment activities are designed to measure how well these types of computational thinking skills, and more general problem solving skills, are affected by taking our introductory courses.

3 How Direct Assessment is Used

We implemented a new assessment activity to try to investigate whether students’ problem solving skills improved during the semester they were in our introductory course. We created a pre-test and post-test directly related to problem solving ability rather than to programming. The pre-test
was given in the second week of the semester and the post-test was given in the thirteenth week of the semester.

The pre-test and post-test problems were designed to be general enough so that they do not require that students have any computing experience; students with good general problem solving skills could solve them. The two problems used were adapted from an archive of the Problems of the Week from the Math Forum (www.mathforum.org). We tried to choose two problems that were approximately equal in difficulty. Our hypothesis was that on average students would demonstrate improved problem solving on the post-test as compared to the pre-test.

The Office of Institutional Research coded each test so that those doing the assessment would not know the identity of the student or whether it was a pre-test or a post-test.

3.1 Pre-Test and Post-Test Instructions

Both the pre-test and the post-test included the following written instructions:

We are more interested in learning how you go about trying to solve the following problem than in whether you actually solve it or not. Explain how you are thinking about the problem as you work on it. Feel free to draw pictures and diagrams if that’s helpful. Please do not discuss this problem with anyone. At the end of the semester we will talk about how to solve it.

The test was administered by the Office of Institutional Research. Oral instructions were also given encouraging students to describe how they were thinking about the problem. Each test consisted of either the Musicians Problem or the Coins Problem described below.

3.2 Musicians Problem

Four musicians are late for a gig. They have 17 minutes to cross a dark bridge to get to the concert. It takes the band’s drummer 10 minutes to cross, the guitarist 5 minutes, the trumpeter 2 minutes, and the singer 1 minute. They only have one flashlight, and no more than two people can cross the bridge at a time.

Because the bridge is so dark, they have to use the flashlight for each trip. Only a person can carry the flashlight. So when two musicians cross to the other side, one must bring the flashlight back over so that the next pair cross.

What order should the musicians cross the bridge to make it to the gig on time?

The key to solving this problem is recognizing that the two slowest musicians (the drummer and the guitarist) must cross together. So first, the two fastest should cross (the singer and the trumpeter), sending one back with the flashlight. Next the two slowest should cross, sending the other remaining fast band member back with the flashlight. Finally the two fastest should again cross for the last time.

3.3 Coins Problem

A friend needed exact change for a juice machine. She only had a $1 bill in her pocket. She asked if I could trade her $1 in change for her bill. I had more than $1 of coins in
my pocket, so I said, "Sure." When I emptied my pocket, however, I found I could not give her exact change for $1.

What is the maximum amount of money in U.S. coins that I can have, which is more than $1, and still not be able to give my friend exact change for a dollar? Explain how you found the maximum amount possible.

Recall that quarters are worth .25 of a dollar, dimes are worth .10 of a dollar, nickels are worth .05 of a dollar, and pennies are worth .01 of a dollar.

There are two solutions to this problem, both equaling $1.19. One solution uses 3 quarters, 4 dimes, and 4 pennies. The other solution uses 1 quarter, 9 dimes, and 4 pennies.

3.4 Rubrics

Student answers were rated based on several rubrics. First, we recorded whether or not they actually solved the problem correctly. Second, we recorded which types of problem solving techniques they employed:

- Using variables to stand for key elements in the problem.
- Using equations to describe relationships amongst key elements.
- Stating constraints that must hold in the solution.
- Drawing diagrams to help understand the problem.

We totaled up how many of these techniques were used on each problem with the maximum being 4 and the minimum being 0. Third, we gave them an overall problem solving effectiveness score from 0 to 4:

- 0: Page was blank, or contained no coherent answer.
- 1: Made an attempt, but used incorrect or incomplete problem solving approaches.
- 2: Used some partially correct problem solving approaches.
- 3: Used some correct problem solving approaches.
- 4: Found the correct solution and clearly showed how they applied problem solving techniques to obtain it.

Note that it was possible for a student to solve the problem correctly, but not get an overall effectiveness score of 4 if they did not show how they discovered the answer.
<table>
<thead>
<tr>
<th>Fall 2010</th>
<th>Number of techniques used</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test: Musicians Problem</td>
<td>1.81</td>
<td>2.23</td>
</tr>
<tr>
<td>Post-test: Coins Problem</td>
<td>1.88</td>
<td>2.83</td>
</tr>
</tbody>
</table>

Table 1: Averages for students in Fall 2010 are shown.

<table>
<thead>
<tr>
<th>Spring 2011</th>
<th>Number of techniques used</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test: Coins Problem</td>
<td>1.52</td>
<td>2.56</td>
</tr>
<tr>
<td>Post-test: Musicians Problem</td>
<td>2.22</td>
<td>2.44</td>
</tr>
</tbody>
</table>

Table 2: Averages for students in Spring 2011 are shown.

### 3.5 Analyzing the Results

The assessment was administered twice, in Fall 2010 to 26 students and in Spring 2011 to 25 students. In Fall 2010, the Musicians Problem was the pre-test and the Coins Problem was the post-test. In Spring 2011, the same two problems were used, but the order was reversed.

Despite efforts to choose two problems that were approximately equal in difficulty, the Coins Problem proved to be easier for the students to solve, regardless of whether it was given early or late in the semester. Nine of 26 students solved the Coins Problem when it was given as the post-test in Fall 2010, and eight of 25 students solved it when it was given as the pre-test in Spring 2011. Only three of 26 students solved the Musicians Problem when it was given as the pre-test in Fall 2010, and similarly only three of 25 students solved it when it was given as the post-test in Spring 2011.

As the data in Table 1 indicate, when the harder problem was given as the pre-test and easier problem was given as the post-test, the rating of students’ overall problem solving effectiveness rose, and the number of problem solving techniques they applied remained about the same.

The more interesting result is to consider what happened when the easier problem served as the pre-test and the harder problem served as the post-test. As the data in Table 2 indicate, when the harder problem was second, the rating of students’ overall problem solving effectiveness stayed about the same. However, the number of problem solving techniques that were tried increased. This is a promising result indicating that when students were stuck on a harder problem they applied more techniques to try to understand how to solve it.

Because the two problems used were not equivalent in difficulty, we do not have definitive evidence that as a result of taking the introductory course students’ problem solving effectiveness improved. Although the quantitative results were not conclusive, as discussed in the next section, the process of doing the assessment has led to several important changes in the curriculum.

### 4 Recommendations for Curricular Changes

As a result of undergoing this assessment process we reflected on how well our introductory course was emphasizing problem solving techniques such as top-down design. We realized that although we covered it in lecture, and instructed students to use it when doing the labs, we had not to that point actually required students to demonstrate that they could effectively use this technique. As
a result, we decided to modify a key lab in the middle of the semester to address this issue more directly.

We broke a one-week lab into a two-week lab with two major parts. Part one focuses on design, and part two focuses on implementation. Students are not allowed to move on to part two until they demonstrate that they have a coherent plan for how to tackle the problem. This consists of a top-down design showing what functions they will write, the input/output specifications for each function, and how these functions will be used to solve the problem.

This change was added to all sections of the introductory course (typically there are three sections each semester). Although the design portion of the lab is harder to grade, all of the course instructors feel that this makes good pedagogical sense, and helps the students understand the importance of abstraction and design in successfully solving problems.

In addition, just the process of doing this assessment activity has led us to become more explicit about describing problem solving techniques as we use them in class. For example, although we have always clearly described top-down design as a problem solving strategy, in the past we may at times have been more implicit about other problem solving techniques we use when presenting solution strategies in class. We now find ourselves being more explicit about stating that what we are applying is a specific problem solving technique (and stating what that technique is) as we demonstrate how to use it to solving computational problems. Being conscious about assessment has resulted in some very positive changes in our courses.

5 Dissemination

We have had ongoing discussions throughout the grant period with all of the Swarthmore faculty participating in the Teagle grant. We have participated in all of the Teagle grant retreats with our Tri-College colleagues. We shared our preliminary results with Swarthmore College faculty in March 2011 at a faculty lunch on Teagle assessment activities. Later this semester we will share our final results with departmental colleagues and consider whether there are any other curricular changes we may want to make in the introductory course.