Test-Driven Learning: Intrinsic Integration of Software Testing into the CS/SE Curriculum

SIGCSE'06

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Outline

- SIGCSE Dilemma
- Test-Driven Learning
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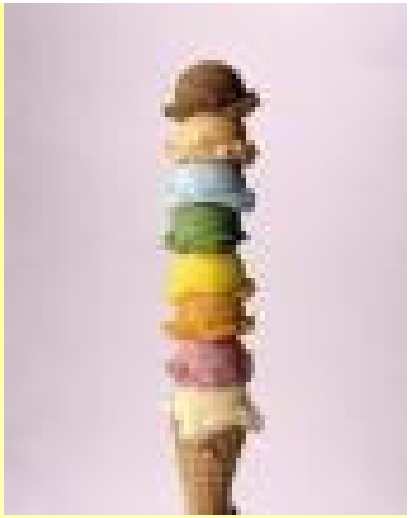
- TDL Benefits
- Evaluation
- Summary

The SIGCSE Dilemma

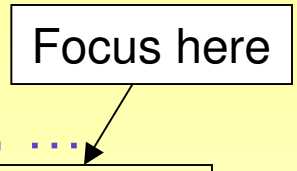


- So many good ideas, so little time
- Software Engineering perspective

  CS != Programming, but
  CS ⊇ Programming
- Many objectives
  - Programming concepts
  - Programming language mastery
  - Good software design
  - Thorough software testing
- Many approaches, sometimes conflicting
  - Objects-, Procedures-, Events-, Everything-first
  - Topical (design course, testing course) or integrated courses

Context

- How do we teach programming?
  - Concepts
    - Algorithms, encapsulation, semantics, …
  - Examples
    - Software presented in a particular language
  - Practice
    - Lab and project assignments



Teach By Example

- Traditional approach in lecture

```
// This function sums the integers from min to max inclusive.
// Pre: min < max
// Post: return-value = min + (min+1) + ... + (max-1) + max
int sum(int min, int max) {
  int sum = 0;
  for(int i=min;i<=max;i++)
    sum += i;
  return sum;
}
int main() {
  cout << sum(3,7) << endl;          //should print 25
  cout << sum(-2,2) << endl;         //should print 0
  cout << sum(-4,-2) << endl;        //should print -9
 }
```

Teach By Example

- Traditional approach in texts or resources

```
void printClassName(Object obj) {
  System.out.println("The class of " + obj + " is " +
                                     obj.getClass().getName());
}
```

From Java 1.5 API

```
#include <iostream>
using namespace std;
int main()
{
  int age;
  cout << "What is your age in years?" << endl;
  cin  >> age;
  cout << "You are at least " << age * 12
       << " months old!" << endl;
}
```

Test-Driven Learning

- Simple Idea
  - Introduce and explore new concepts through automated unit tests
- Inspired by
  - Testing Patterns In Beck's "TDD: by Example"
    - Explanation Test
      - ask for and provide explanations in terms of tests
    - Learning Test
      - if you want to use a new method, class, or API, first write tests to learn how it works

Teach By Example

- TDL Approach

```
#include <cassert>
// This function sums the integers from min to max inclusive.
// Pre: min < max
// Post: return-value = min + (min+1) + ... + (max-1) + max
int sum(int min, int max) {
  int sum = 0;
  for(int i=min;i<=max;i++)
    sum += i;
  return sum;
}
int main() {
  assert(sum(3,7)==25);
  assert(sum(-2,2)==0);
  assert(sum(-4,-2)==-9);
 }
```

Teach By Example

- Traditional Approach

From Java 1.5 API

```
void printClassName(Object obj) {
  System.out.println("The class of " + obj + " is " +
                                        obj.getClass().getName());
}
```

- TDL Approach

```
void testClassName1() {
  Integer i = new Integer(5);
  assert i.toString().equals("5");
  assert i.getClass().getName().equals("java.lang.Integer");
}
```

```
void testClassName2() {
  ArrayList al = new ArrayList();
  assert al.toString().equals("[]");
  assert al.getClass().getName().equals("java.util.ArrayList");
}
```

TDL Throughout Curriculum

- Any time you present an example with code, you can consider applying TDL

```
#include <cassert>
class Exams { . . . };
int main()
{
    run_tests();
}
void run_tests()
{
  { //test 1 Minimum of empty list is 0
    Exams exam1;
    assert(exam1.getMin() == 0);
  } //test 1
  { //test 2
    Exams exam1;
    exam1.addExam(90);
    assert(exam1.getMin() == 90);
  } //test 2
}
```

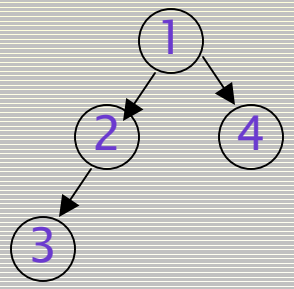
Early examples might use simple asserts isolated in a test procedure

TDL in Data Structures

```
import java.util.Enumeration;
import javax.swing.tree.DefaultMutableTreeNode;
import junit.framework.TestCase;

public class TreeExploreTest extends TestCase {
    public void testNodeCreation() {
      DefaultMutableTreeNode node1 = new DefaultMutableTreeNode("Node1");
      DefaultMutableTreeNode node2 = new DefaultMutableTreeNode("Node2");
      DefaultMutableTreeNode node3 = new DefaultMutableTreeNode("Node3");
      DefaultMutableTreeNode node4 = new DefaultMutableTreeNode("Node4");
      node1.add(node2);
      node2.add(node3);
      node1.add(node4);
      Enumeration e = node1.breadthFirstEnumeration();
      assertEquals(e.nextElement(),node1);
      assertEquals(e.nextElement(),node2);
      assertEquals(e.nextElement(),node4);
      assertEquals(e.nextElement(),node3);
    }
}
```

Later examples might use JUnit or xUnit



TDL in Static Analysis

```
public void testFlowCombinations() {
  LiveVariableAnalyzer lva = new LiveVariableAnalyzer();
  Set flow = new HashSet();
  assertTrue(flow.isEmpty());
  lva.flow("[x:=3]1; while [x<9]2 do [y:=x]3",flow);
  assertEquals(flow.size(),3);
  assertTrue(flow.contains(new Pair(1,2)));
  assertTrue(flow.contains(new Pair(2,3)));
  assertTrue(flow.contains(new Pair(3,2)));
}
public void testOneLV() {
  LiveVariableAnalyzer lva = new LiveVariableAnalyzer();
  lva.setProgram("[x:=5]1;[y:=x]2");
  lva.analyze();
  assertTrue(lva.getEntry(1).isEmpty());
  assertTrue(lva.getExit(1).contains(new Character('x')));
  assertTrue(lva.getEntry(2).contains(new Character('x')));
  assertTrue(lva.getExit(2).isEmpty());
}
```

TDL has been applied in graduate and corporate training courses

Potential Benefits of TDL

- Teach testing for free
  - Replace current approach instead of add to it
- Improve student design skills
  - Focus on use (interface and behavior) before implementation

```
assert(sum(3,7)==25);
```

- Improve student testing skills
  - Students emulate professors
- Improve student success on projects
  - More and earlier testing reduces defects and improves likelihood of delivering solution

Evaluation

- Short controlled experiment conducted
- CS1 Spring 2005 at University of Kansas

Treatment	Students	Exam 1 100 total	Quiz 10 total
TDL	13	86.15	7.84
Non-TDL	14	86.71	7.14

Similar exam scores **prior** to treatment

TDL group scored 10% higher

- Beware not to draw conclusions from such a small study!

Summary

- Test-Driven Learning
  - is a simple approach of presenting examples with automated tests
  - takes no extra time
  - can be applied at all levels of the curriculum
  - requires minimal tool support or configuration yet scales well
  - may encourage students to write more tests
  - may improve student testing skills
  - may improve student design skills

Resources

- Sample labs and project assignments available at http://www.simexusa.com/tdl/
- Questions or contributions: djanzen@ku.edu

Acknowledgements

- SIGCSE Special Projects Award