Teaching Software Testing with Automated Feedback

James Perretta and Andrew DeOrio, University of Michigan

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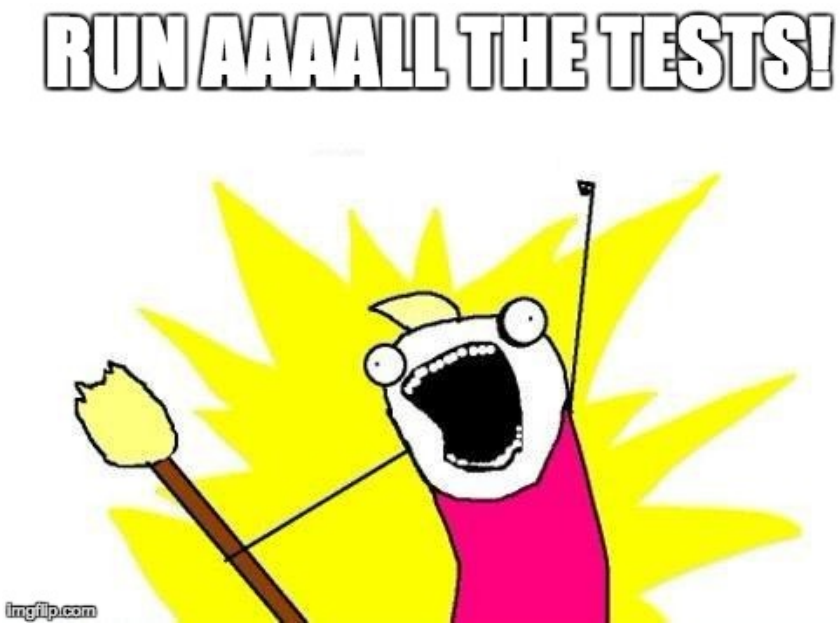
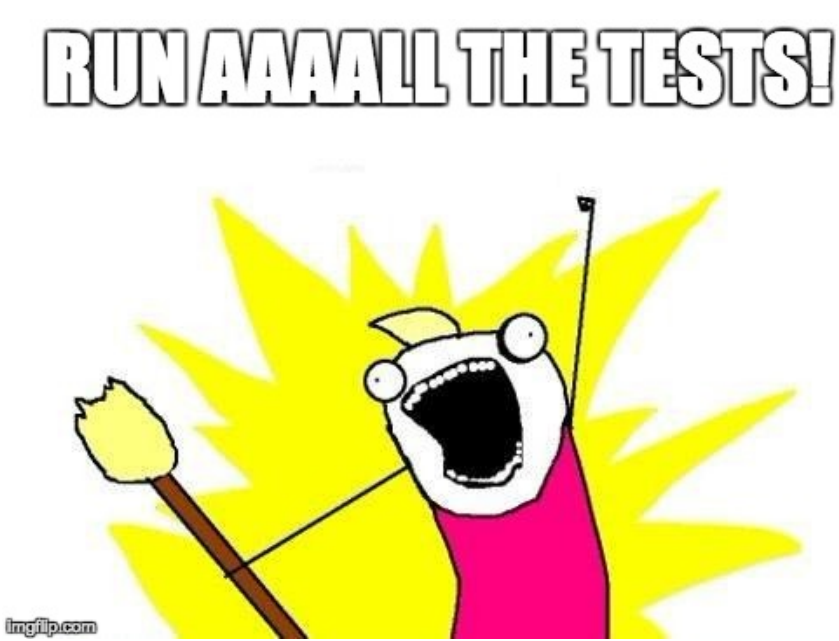
How important is it for your students to learn software testing?

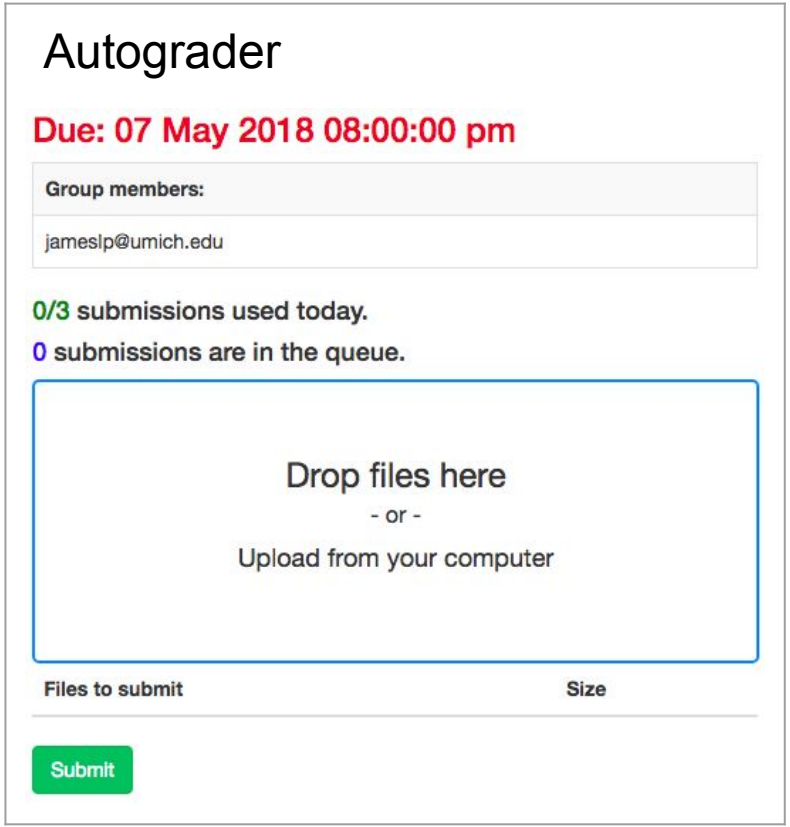


How do your students feel about it?



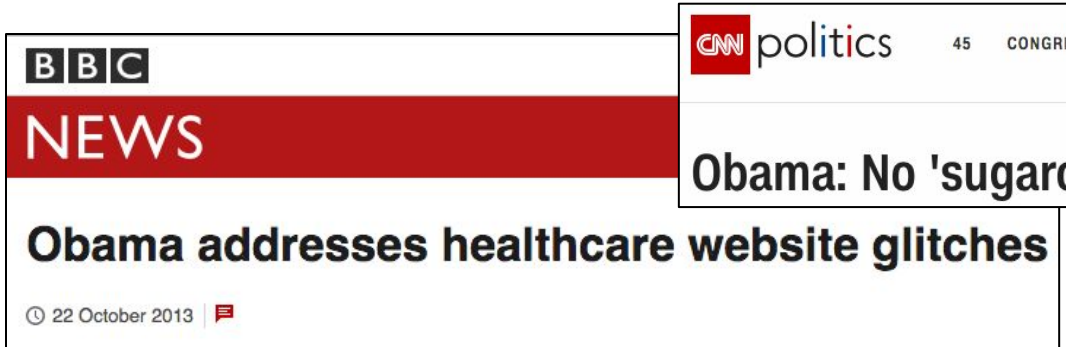
Motivation

- Software testing is important!
  - But little time spent teaching it. (Edwards 2003)
- Testing takes practice.
- Automated grading becoming more common in CS courses.



Software Testing!

- 41% of IT budgets spent on QA and testing. (Hannigan & Walker 2015)
- HealthCare.gov
  - Launched Oct. 1, 2013, standard Web 2.0 app
  - Many users couldn't register, combination of high load and software issues
  - Some applications submitted with missing info

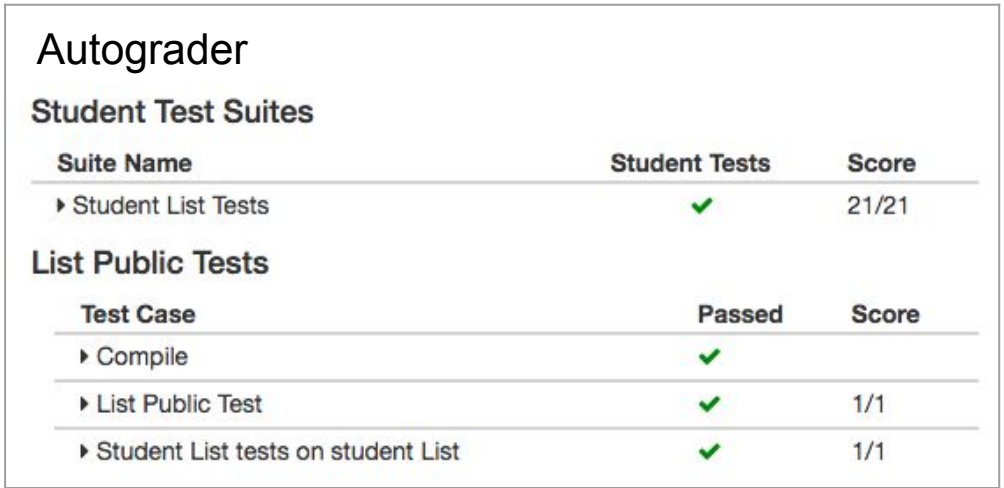


Teaching Software Testing

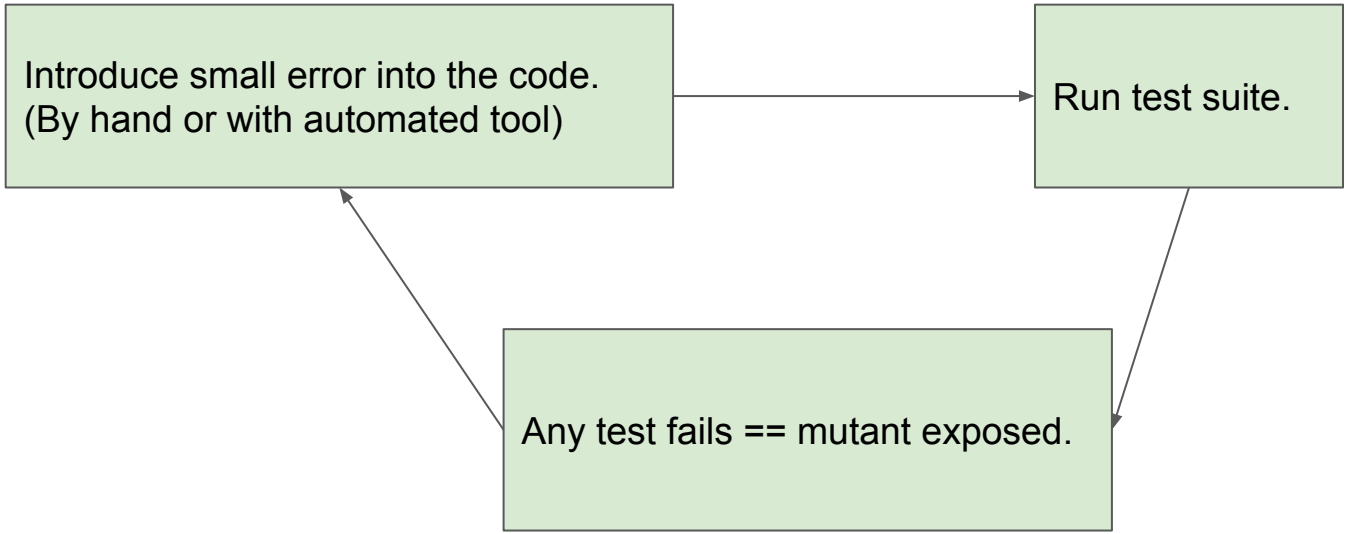
- Process-driven approaches:
  - Test-driven development (Desai et al 2008)
    - Test early, test often
  - SPRAE: Specification, Premeditation, Repeatability, Accountability, Efficiency (Jones & Chatman 2001)
    - Systematic approach to writing tests

Automatically Grading Student Tests

- Gives students immediate feedback on their tests.
- Test quality metrics:
  - Coverage: “What percentage of source code is exercised?”
  - Whether a test suite is free of **false positives**
  - Mutation Testing: “How good are tests at catching real bugs?” (**true positives**)



Mutation Testing



- Mutant: One copy of code with bug added.
- A high-quality test suite should expose more mutants than a low-quality test suite. (Jia & Harman 2010)

Research Questions

- Does automated feedback improve students' ability to write high-quality test cases?
- What type of feedback best encourages student learning of software testing?

Goal: Conduct an experiment to measure the effectiveness of automated feedback policies.

Methods: Course Overview

- Population: 1,556 students over two semesters of a second-semester programming course.
- 3 hrs lecture and 2 hrs lab per week.
- Lecture and lab sections synchronized, students could attend any section and learn same material.
- Both semesters in our study synchronized for content and organization.

Methods: Programming Projects

- 5 programming projects total (we used 3 in our study):
  - Implement one or more abstract data types (ADTs).
  - Writing unit tests for the ADTs.
  - A command-line program using the ADTs.
  - Students could work alone or with a partner

	Project 1	Project 2	Project 3	Project 4	Project 5
Instructor LOC	140	301	595	372	495

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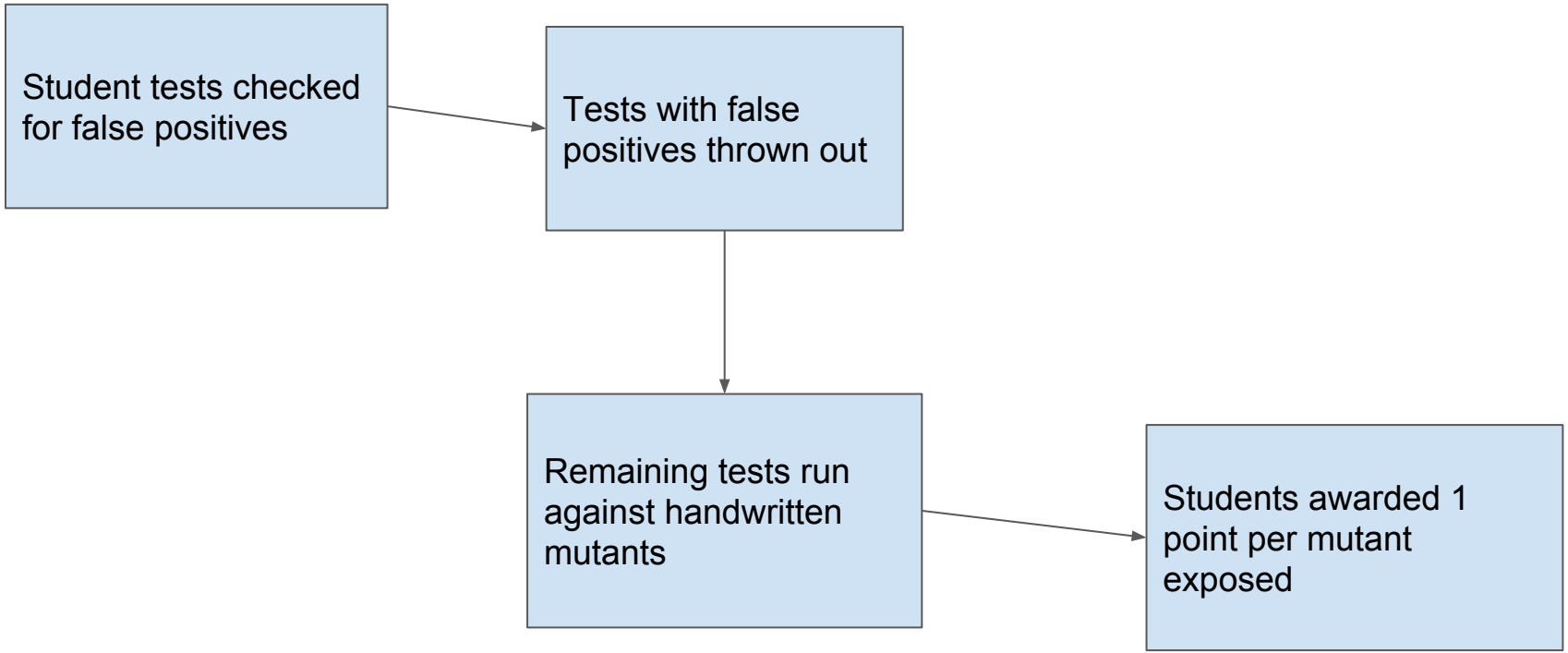
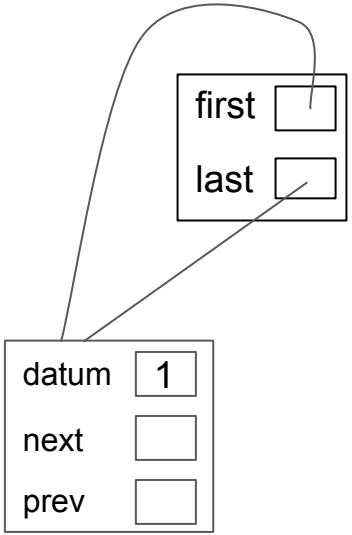
	Project 1	Project 2	Project 3	Project 4	Project 5
Instructor LOC	140	301	595	372	495
Average Student LOC	165	388	857	378	533

Methods: Student Test Evaluation



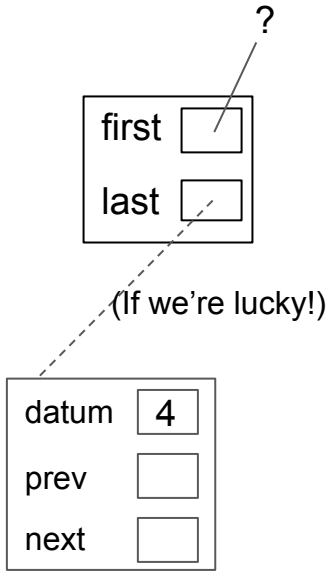
Example: Instructor-written Mutant

```
// CORRECT implementation.
template <typename T>
void List<T>::push_back(const T &datum) {
  Node *np = new Node;
  if (empty()) {
    np->prev = 0;
    first = np;
  } else {
    np->prev = last;
    last->next = np;
  }
  np->next = 0;
  np->datum = datum;
  last = np;
  ++num_nodes;
}
```




```
// BUGGY implementation: Fails if list is empty.
template <typename T>
void List<T>::push_back(const T &datum) {
  Node *np = new Node;

  np->prev = last;
  last->next = np;
  np->next = 0;
  np->datum = datum;
  last = np;
  ++num_nodes;
}
```



Methods: Control Group

- Students enrolled in first semester.
- Same feedback on all three projects

Autograder

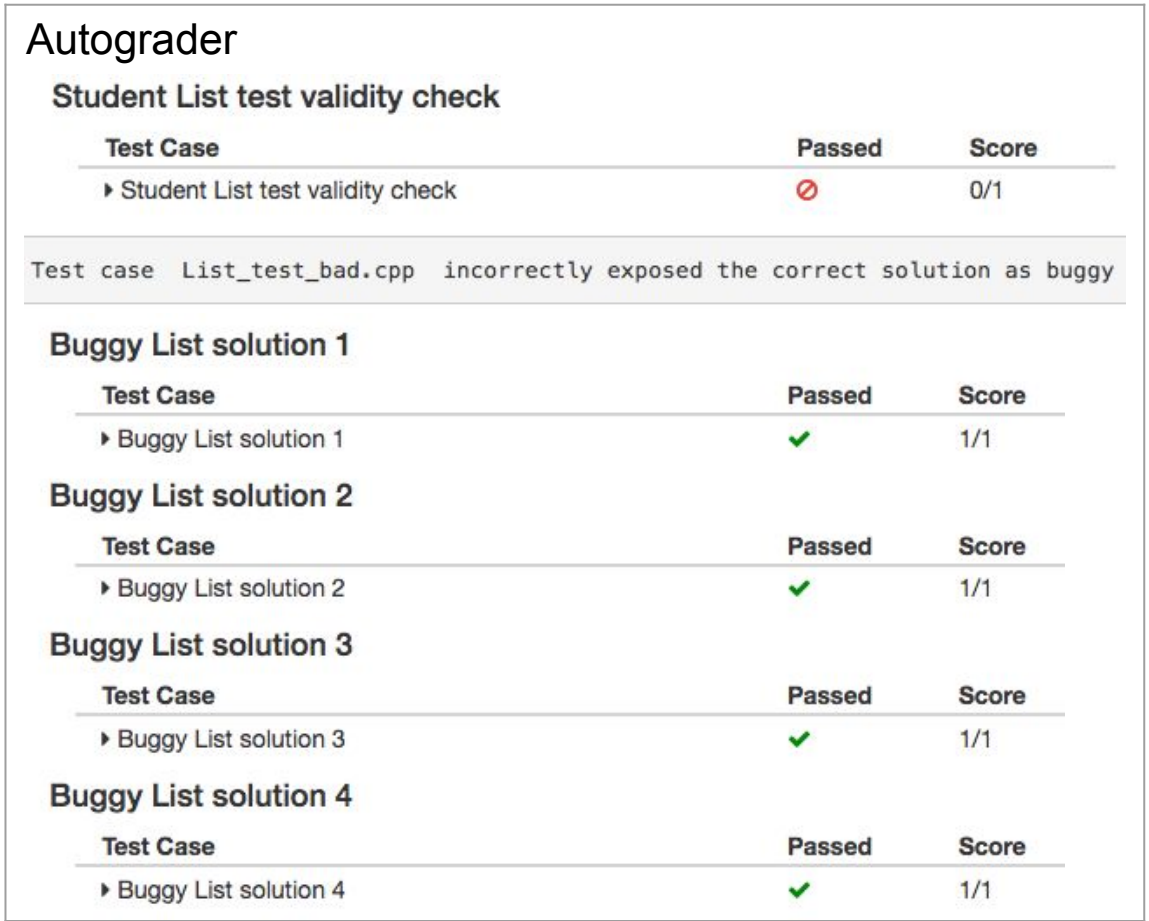
Student List test validity check

Test Case	Passed	Score
▸ Student List test validity check	⊘	0/1

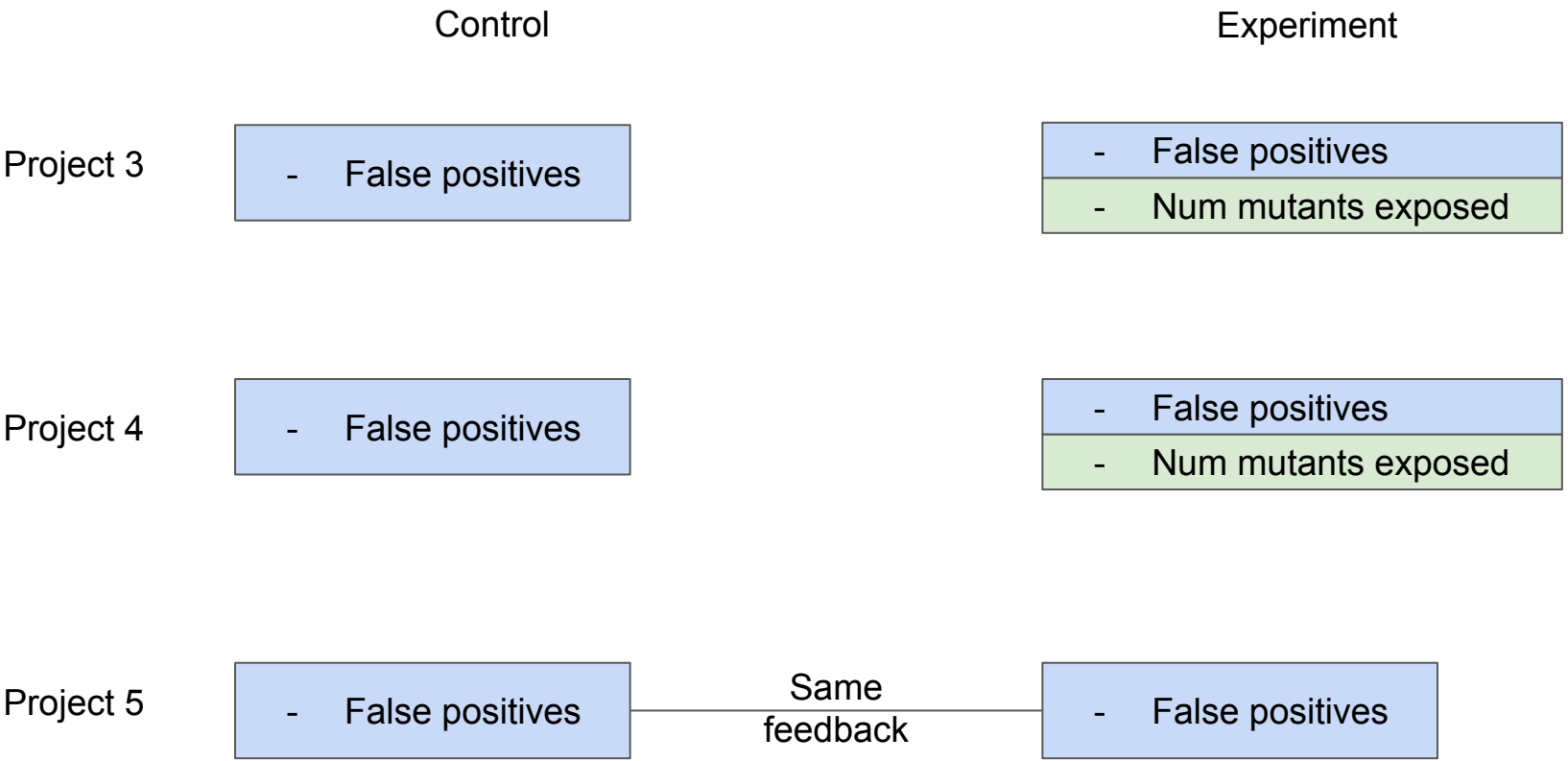
```
Test case  List_test_bad.cpp  incorrectly exposed the correct solution as buggy
```

Methods: Experiment Group

- Students enrolled in second semester.
- Additional feedback on first 2 projects.



Methods: Control & Experiment Groups



Methods: Variables

- Independent variables:
  - Test case feedback type (control and experiment groups)
  - Partnership status
  - GPA (control for this variable)
- Dependent variables:
  - Student test case quality (percentage of mutants exposed)

We used ANOVA to look for significant associations.

Results: Significance

	Project 3				Project 4				Project 5			
	df	Sum Sq.	F	**PR(>F)**	df	Sum Sq.	F	**PR(>F)**	df	Sum Sq.	F	**PR(>F)**
Feedback	1	2.2	40.95	**2.34e-10**	1	3.43	114.92	**1.64e-25**	1	0.46	12.04	**5.44e-04**
Partner	1	3.03	56.32	1.31e-13	1	1.59	53.38	5.45e-13	1	1.24	32.29	1.75e-08
Feedback x Partner	1	0.01	0.11	7.39e-01	1	0.27	8.97	2.81e-03	1	0.14	3.6	5.82e-02
GPA	1	25.91	481.46	3.19e-88	1	11.76	394.25	1.08e-74	1	9.66	251.18	1.36e-50
GPA x Feedback	1	0.02	0.34	5.60e-01	1	0.0	0.12	7.26e-01	1	0.04	1.02	3.14e-01
GPA x Partner	1	0.0	0.0	9.63e-01	1	0.15	4.9	2.71e-02	1	0.0	0.02	8.88e-01
GPA x Feedback x Partner	1	0.0	0.07	7.87e-01	1	0.07	2.4	1.21e-01	1	0.06	1.56	2.11e-01
Residual	1056	56.83			1045	31.17			991	38.12		

Significant association b/w feedback type and test quality on all 3 projects.

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- Significant association b/w partnership status and test quality on all 3 projects.
- Magnitude of association comparable to that of feedback type.

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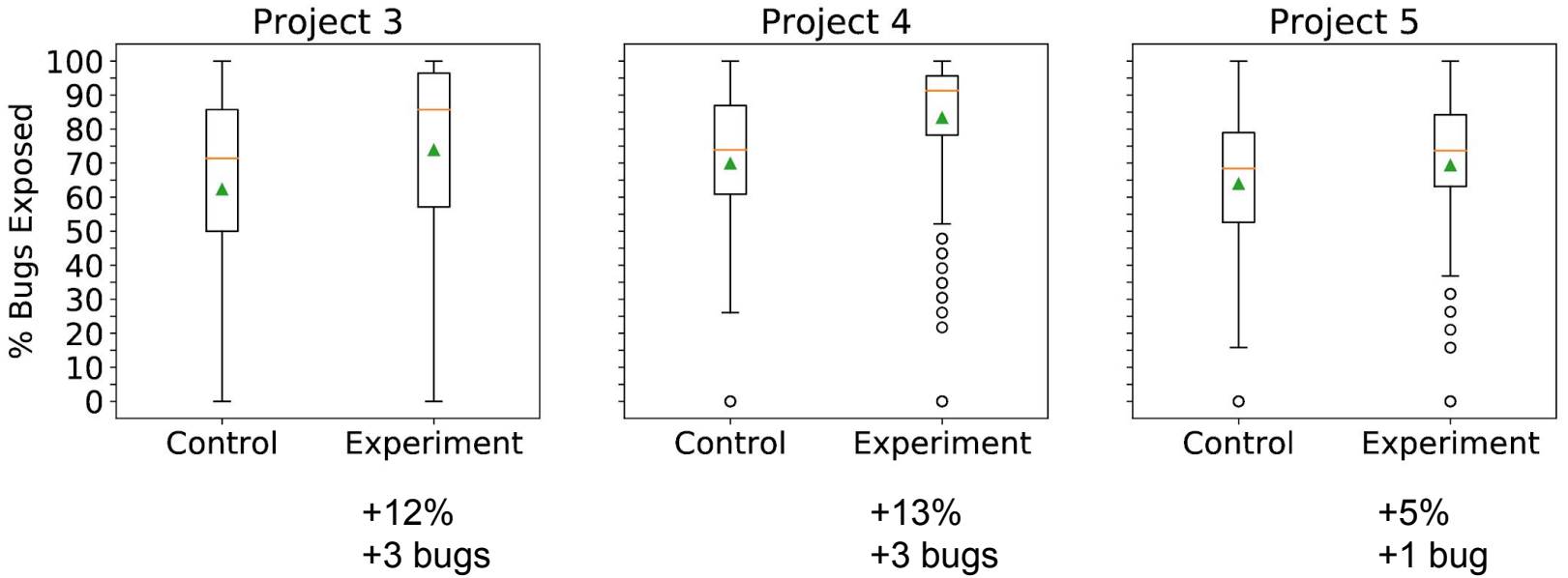
Residual	1056	56.83			1045	31.17			991	38.12		

- Control for GPA
- Significant association b/w GPA and test quality on all 3 projects.

Results: Test Case Quality vs. Feedback Type



+12%
+3 bugs

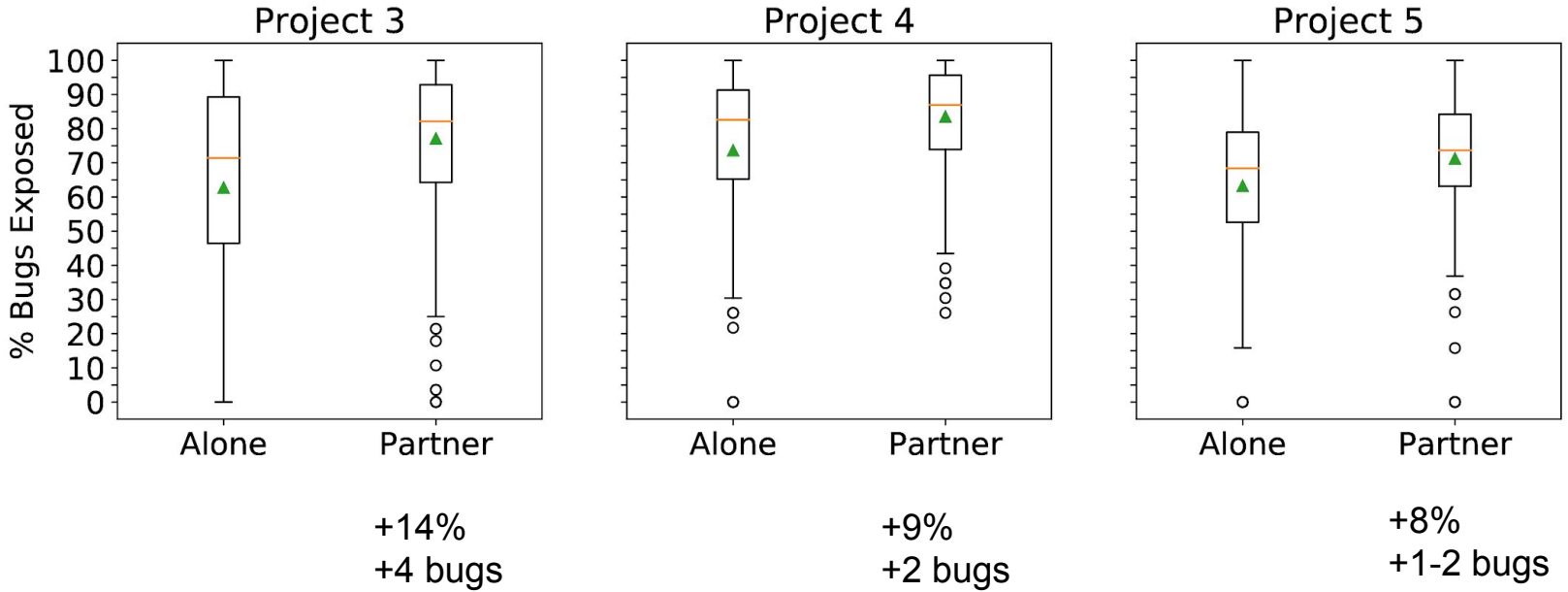
+13%
+3 bugs

+5%
+1 bug

(Additional feedback removed)

All 3 differences in mean are statistically significant.

Results: Test Case Quality vs. Partnership



All 3 differences in mean are statistically significant.

Limitations

- Projects in our experiment may have varied in difficulty.
- Control and experiment groups came from different semesters of same course.
  - Note: Both semesters were very consistent in organization and material.
- Students chose whether to work with a partner, who their partner would be.

Conclusion

- Students who received additional feedback on their test cases wrote higher-quality test cases, even after augmented feedback was taken away.
- Students who worked with a partner consistently wrote higher-quality test cases.
- Our work can help inform CS educators in their decisions on how to evaluate student tests and what automated feedback to provide.