COMPUTER SCIENCE
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# Assessing Incremental Testing Practices and Their Impact on Project Outcomes

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# Study Context

- Third year (post-CS2) Data Structures & Algorithms course
- 157 students
- 4 assignments
  - *Median 1.4 kLOC*
  - *3-4 weeks long*
- 415 implementations (unbalanced)

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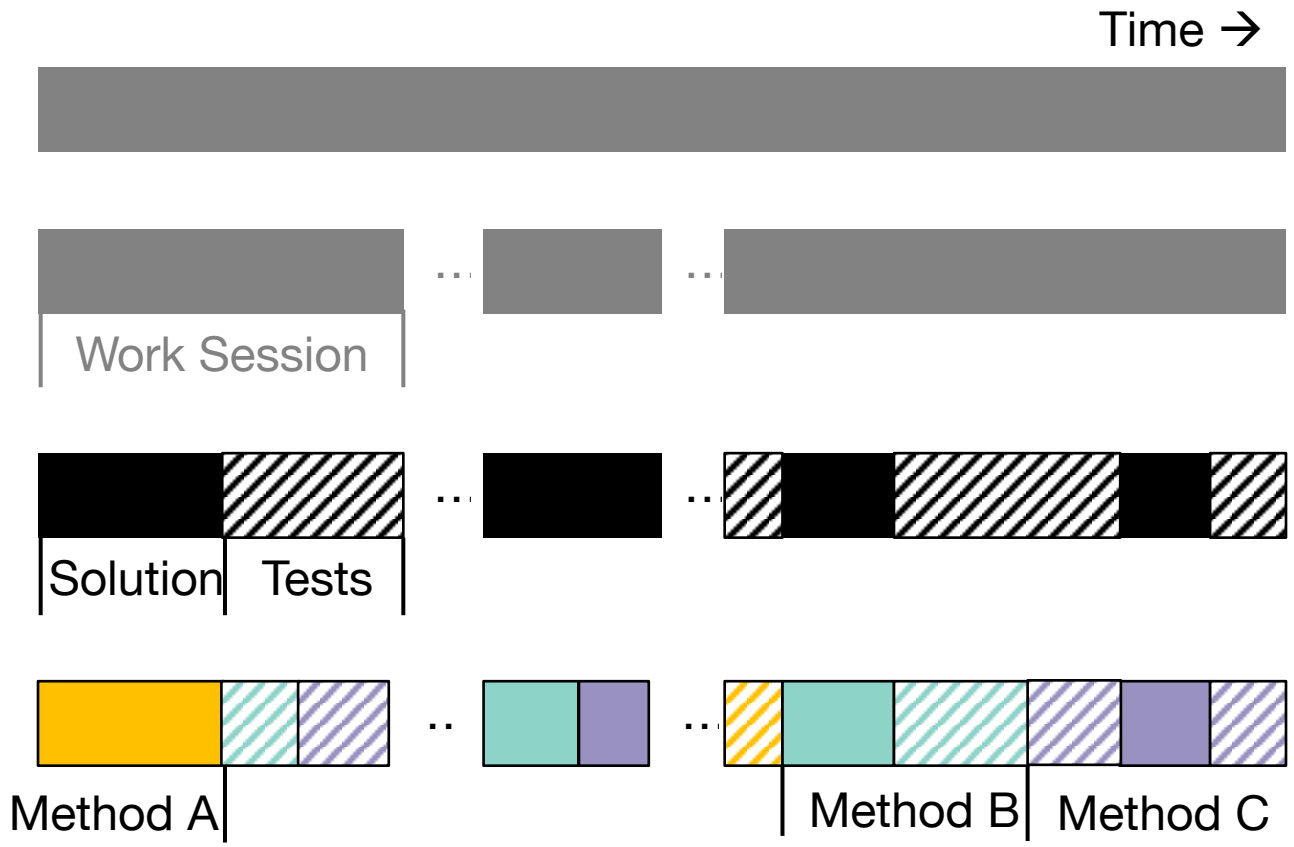
# Contributions

- Family of metrics to assess incremental testing

- Empirical study
  1. *How does the **balance** of testing effort relate to project outcomes?*
  2. *How does the **sequence** of testing effort relate to project outcomes?*

# Better Feedback on Process

## Programming effort




## Feedback

Correctness: 100%
Code coverage: 89%

Procrastination: 75% [1]

Balance of testing

Thoroughness of testing

[1] *Quantifying Incremental Development Practices and Their Relationship to Procrastination*. Ayaan M. Kazerouni, Stephen H. Edwards, and Clifford A. Shaffer

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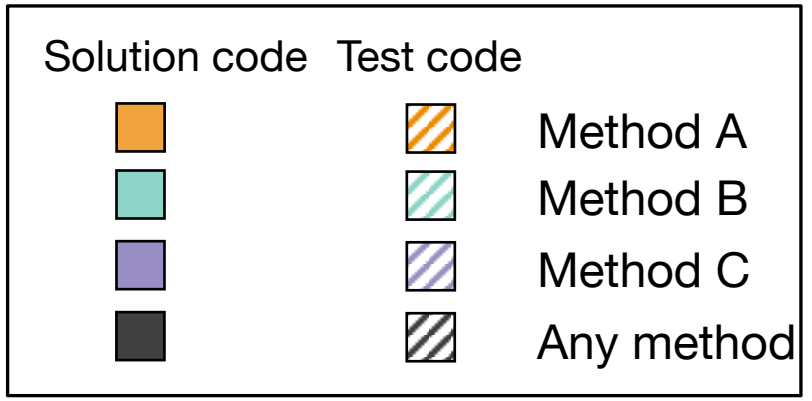
# Assessing Incremental Testing

# Proposed Metrics of Testing Effort

Synthetic example: sequence of developer activity



# Proposed Metrics of Testing Effort

Synthetic example: sequence of developer activity

Project-wide Overall Testing Effort

$$\frac{T}{S+T}$$

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Synthetic example: sequence of developer activity

Project-wide Overall Testing Effort

$$\frac{T}{S+T}$$

Project-wide per-Session Testing Effort

$$median\left\{\frac{T_s}{S_s+T_s}\right\}$$

# Proposed Metrics of Testing Effort

Synthetic example: sequence of developer activity

Solution code Test code

Method A

Method B

Method C

Any method

Project-wide Overall Testing Effort

$$\frac{T}{S+T}$$

Project-wide per-Session Testing Effort

$$median\left\{\frac{T_s}{S_s+T_s}\right\}$$

Method-specific Overall Testing Effort

$$median\left\{\frac{T_m}{S_m+T_m}\right\}$$

# Proposed Metrics of Testing Effort

Synthetic example: sequence of developer activity

| Solution code | Test code | |
|---|---|---|
| | | Method A |
| | | Method B |
| | | Method C |
| | | Any method |

Project-wide Overall Testing Effort

$$\frac{T}{S+T}$$

Project-wide per-Session Testing Effort

$$median\left\{\frac{T_s}{S_s+T_s}\right\}$$

Method-specific Overall Testing Effort

$$median\left\{\frac{T_m}{S_m+T_m}\right\}$$

Method-specific per-Session Testing Effort

$$median\left\{median\left\{\frac{T_{ss}}{S_{ss}+T_{ss}}\right\}_{m}\right\}$$

# Proposed Metrics of Testing Effort

Synthetic example: sequence of developer activity

Solution code Test code

Method A
Method B
Method C
Any method

Project-wide Overall Testing Effort

$$\frac{T}{S+T}$$

Project-wide per-Session Testing Effort

$$median\left\{\frac{T_s}{S_s+T_s}\right\}$$

Method-specific Overall Testing Effort

$$median\left\{\frac{T_m}{S_m+T_m}\right\}$$

Method-specific per-Session Testing Effort

$$median\left\{median\left\{\frac{T_s}{S_s+T_s}\right\}_m\right\}$$

Method-specific Overall Sequence of Testing Effort

= Method is “finalised”

$$median\left\{\frac{T_{before}}{T_{before}+T_{after}}\right\}$$

# Motivating Example from Fall 2016

Fig. 1: Good Test Writing Process

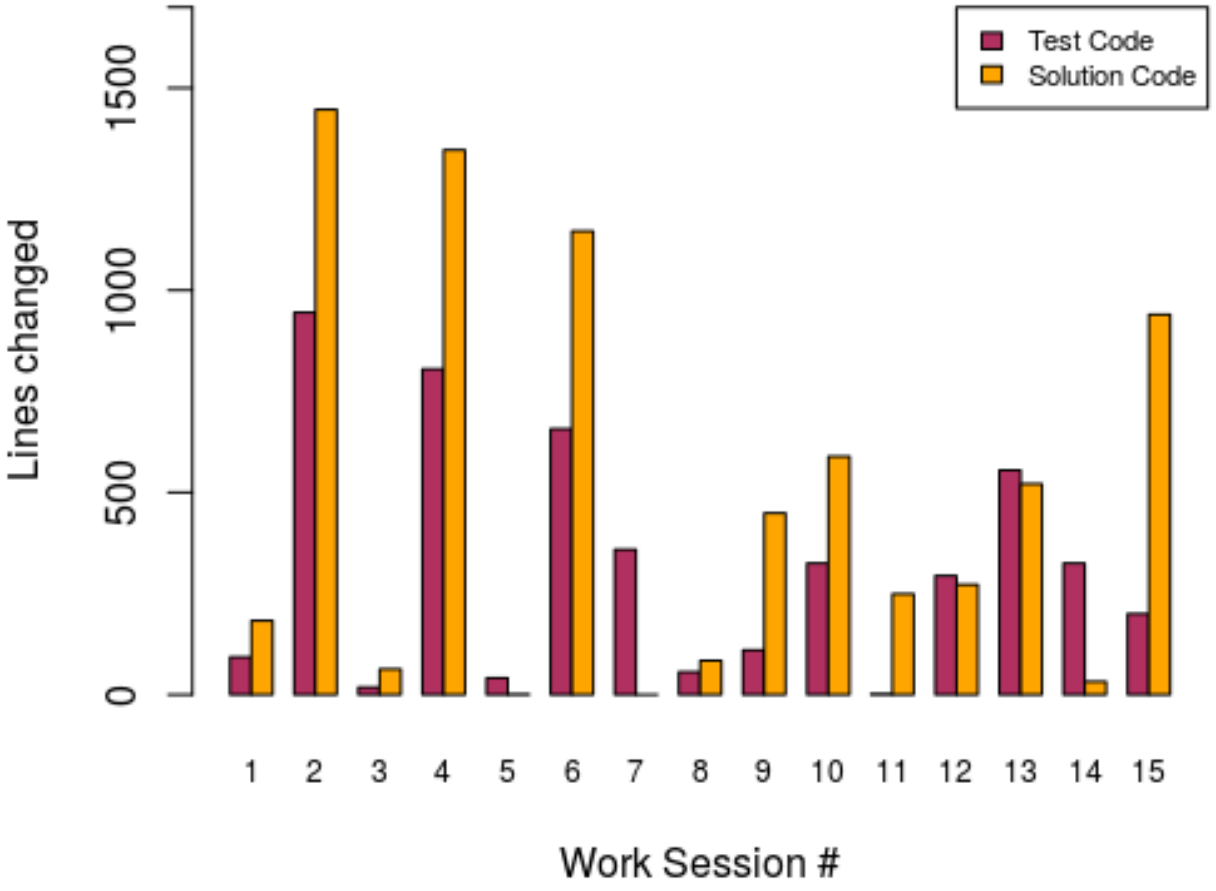
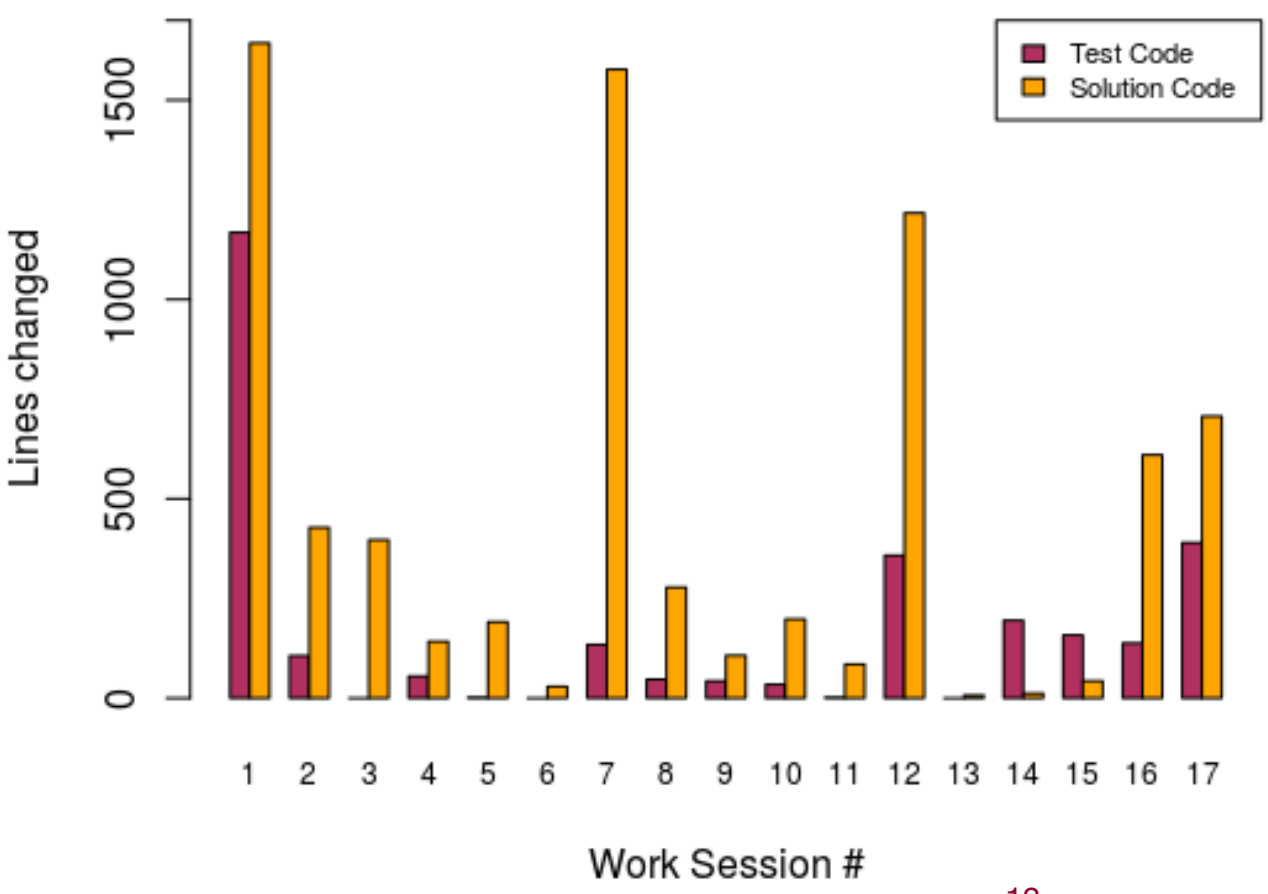



Fig. 2: Poor Test Writing Process



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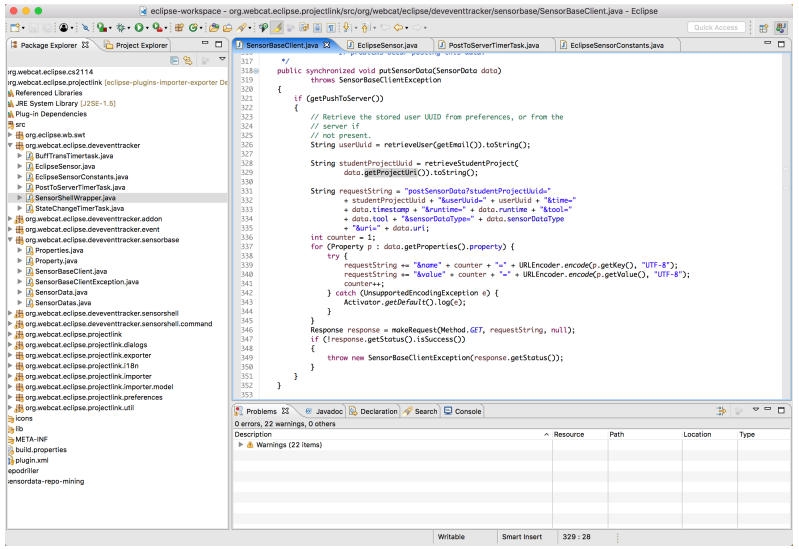
# Empirical Study

# Data Collection

- 400+ project implementations



**Edit Event**

Type: Edit
Time: 1477672862
Snapshot Id: 23479b3

| Type | Size | Time |
|---|---|---|
| Change in method **`insertFront`** | +5 | 12:41:02 |
| Change in method **`getSize`** | +1 | 12:41:02 |
| Change in test for **`insertFront`** | +3 | 12:41:02 |

# Study Design

- Fixed effects: 5 measures of testing effort
- Random effects: students, assignments
- Outcome variables:
  - ***Correctness, m***easured by the percentage of reference tests passed
  - ***Code coverage*** achieved by the student's own test suite

Mixed effects model: repeated measures for each student, and for each assignment.

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# Results

# Project-wide Overall Testing Effort


Expectation: Positive relationship with correctness and code coverage.

| Correctness | | Code Coverage | |
|---|---|---|---|
| Regression estimate | *p* | Regression estimate | *p* |
| 0.30 | < 0.001 * | 0.23 | < 0.001 * |

- Implementations with a higher project-wide testing effort achieved:
  - Higher semantic correctness
  - Higher code coverage

# Project-wide per-Session Testing Effort


Expectation: Positive relationship with correctness and code coverage.

| Correctness | | Code Coverage | |
|---|---|---|---|
| Regression estimate | *p* | Regression estimate | *p* |
| 0.30 | 0.005 * | 0.12 | 0.008 * |

- Implementations with higher testing effort within each work session achieved
  - Higher semantic correctness
  - Higher code coverage

# Motivating Example (Reprise)

Fig. 1: Good Test Writing Process

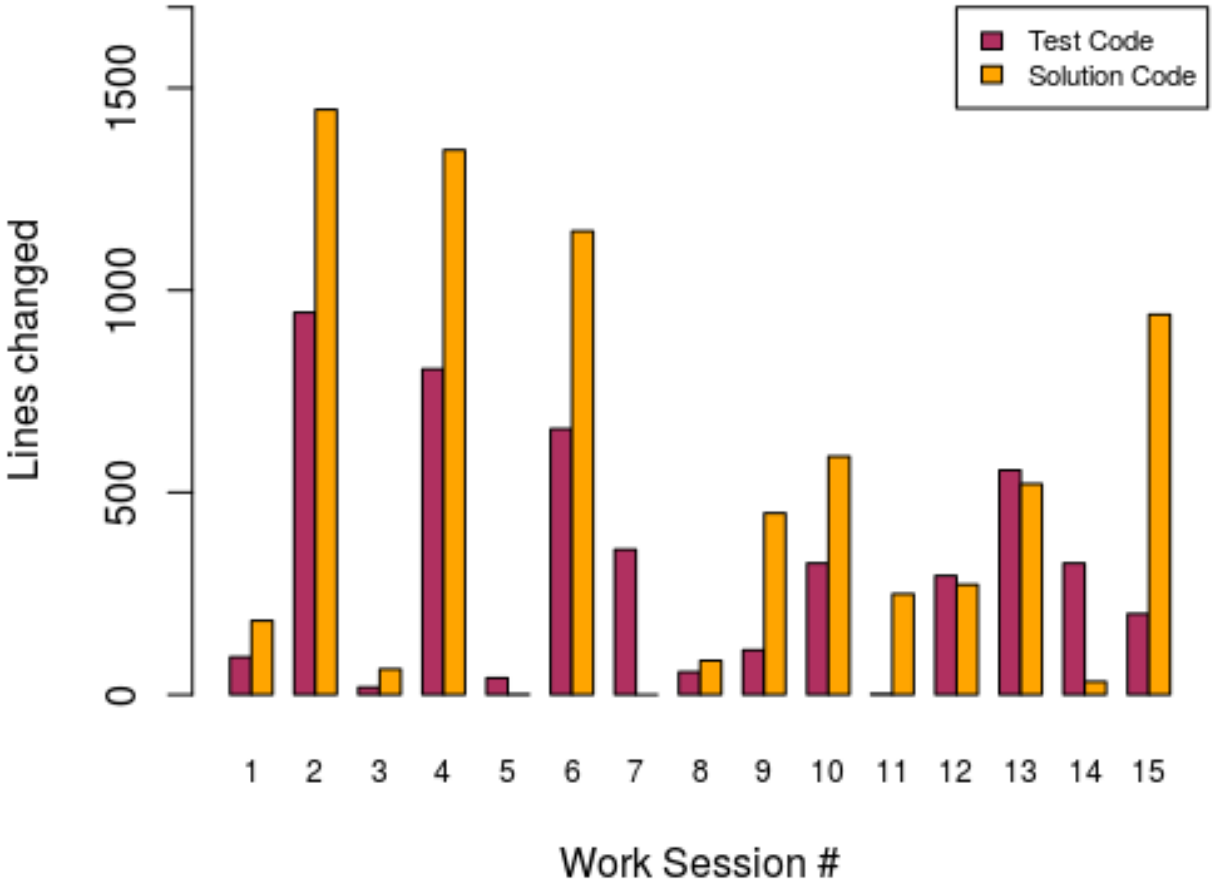
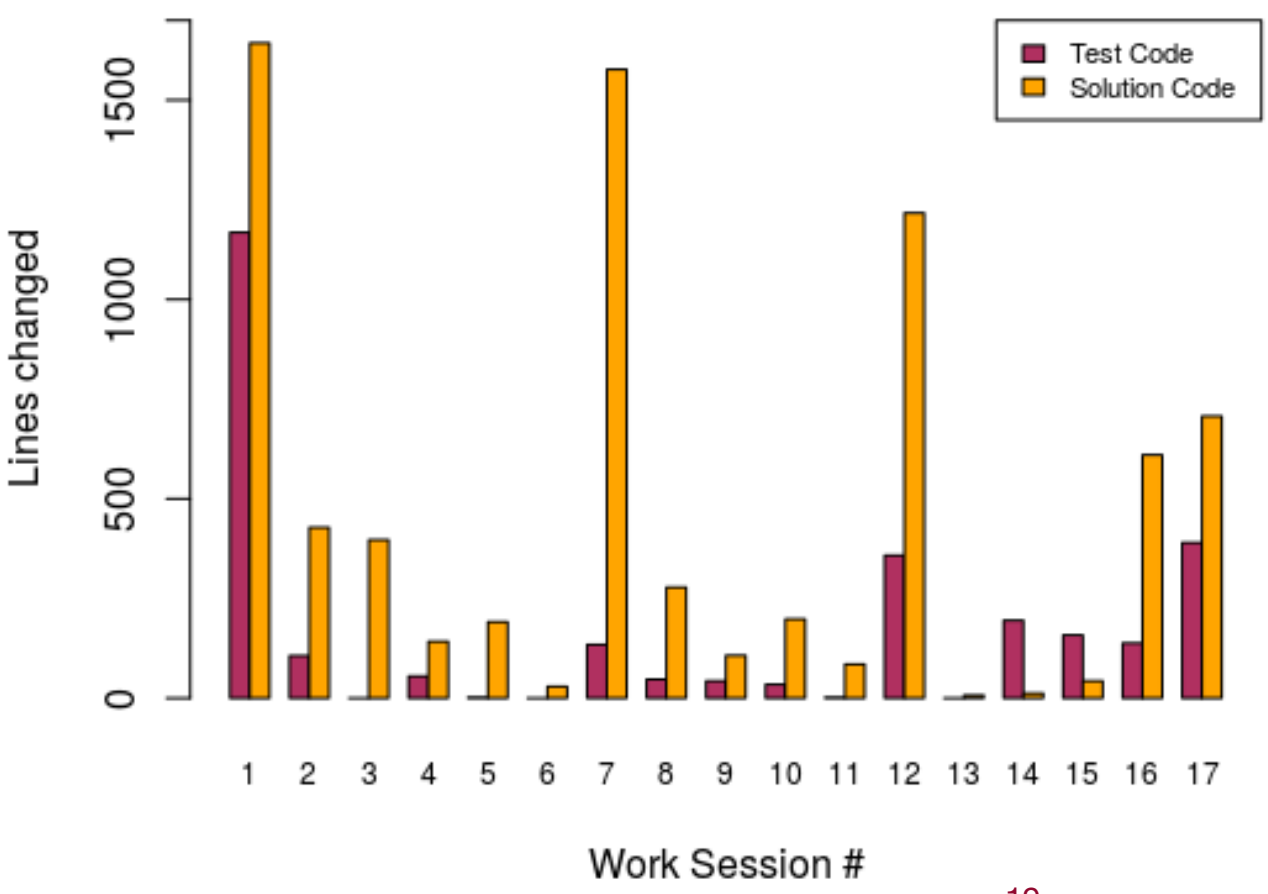



Fig. 2: Poor Test Writing Process



# Method-specific Sequence of Testing Effort

Expectation: *Positive* or *no relationship* with project outcomes.

| Correctness | | Code Coverage | |
|---|---|---|---|
| Regression estimate | p | Regression estimate | p |
| -- | 0.10 | –0.06 | < 0.001 * |

- Implementations where a higher proportion of testing for a method was done *before the method was finalised*, achieved:
  - No significant change in correctness
  - Lower code coverage

# Putting It All Together

1

- Correctness
- Code Coverage

2

- Correctness
- Code Coverage

3

- ? Correctness
- Code Coverage

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# Closing Remarks

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# Summary

- Quantified test-writing practices
- Empirical study
  - *Higher testing effort is good (whole project and per-method)*
  - *Higher testing effort per work session is good*
  - *No such relationship on a per-method basis*
  - *Higher testing effort before finalizing relevant solution code*
    - Does not lead to improved correctness
    - Negative relationship with code coverage
- Next step: Design and deploy automated interventions for continuous feedback

ayaan@vt.edu https://github.com/ayaankazerouni/incremental-testing

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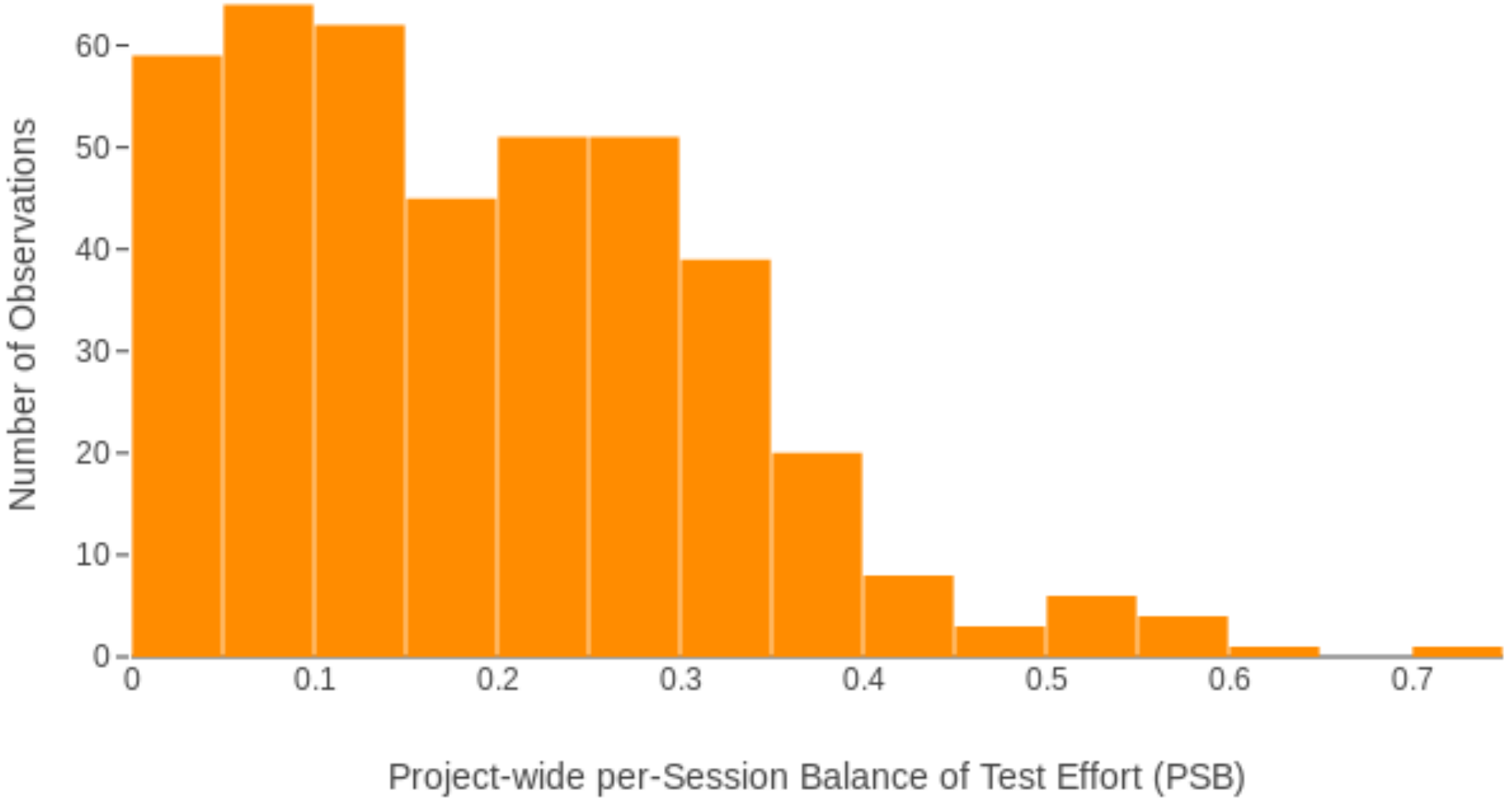
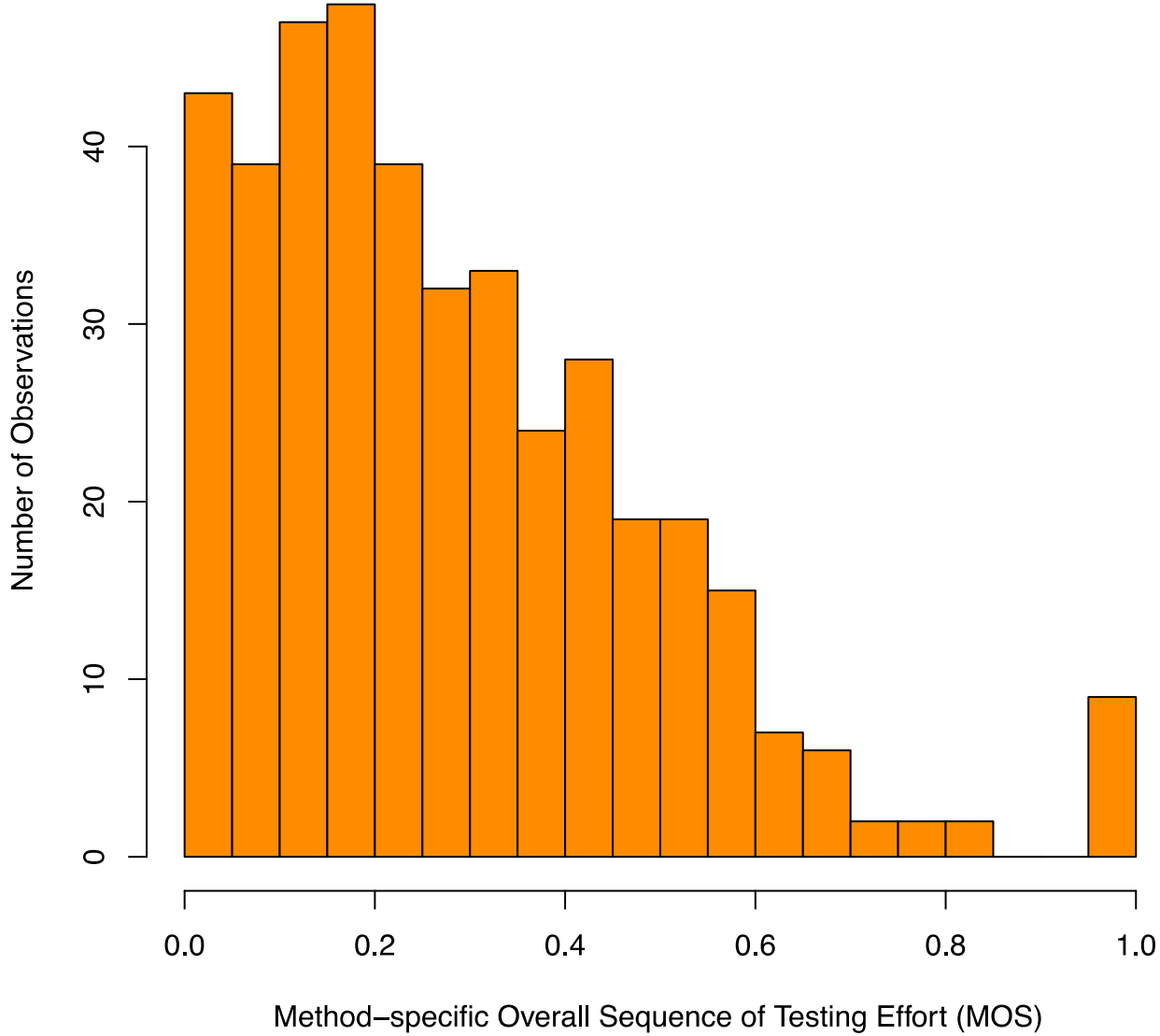
# Bonus Material

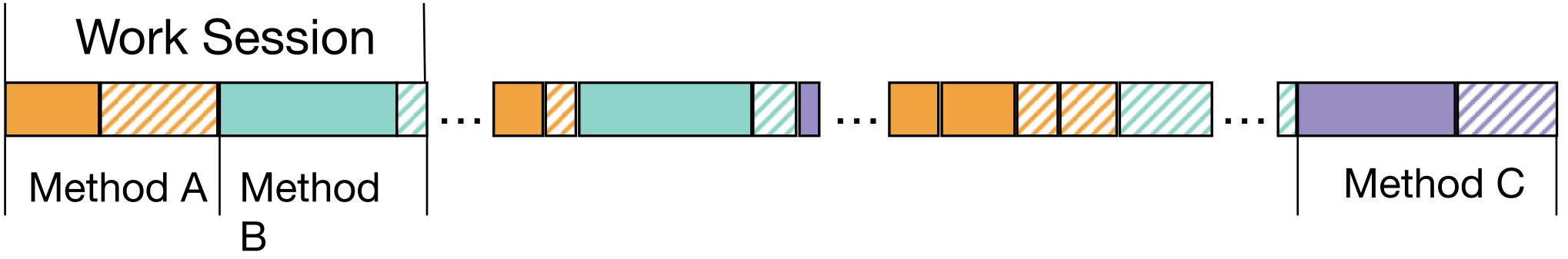
# Per-session Testing Effort: Distribution



# Method-specific Sequence of Testing Effort



# Method-specific per-Session Testing Effort




Expectation: Positive relationship with both project outcomes.

| Correctness | | Condition Coverage | |
|---|---|---|---|
| Regression estimate | *p* | Regression estimate | *p* |
| -- | 0.10 | 0.23 | < 0.001 * |

- Higher testing effort per-method, per-session achieved:
  - Higher condition coverage
  - No significant change in

# Mixed effects model (Process)

| | Correctness | | Code Coverage | |
|---|---|---|---|---|
| **Metric** | Regression estimate | p | Regression estimate | p |
| Testing per-Session | 0.30 | 0.005 * | 0.12 | 0.008 * |
| Testing per-Session per-Method | -- | 0.10 | 0.09 | 0.002 * |
| Sequence of testing | -- | 0.62 | -0.06 | 0.02 * |

# Mixed effects model (Overall)

| | Correctness | | Code Coverage | |
|---|---|---|---|---|
| **Metric** | Regression estimate | p | Regression estimate | P |
| Testing | 0.30 | < 0.001 * | 0.23 | < 0.001 * |
| Testing per-Method | -- | 0.12 | -- | 0.41 |
| Testing per-Session | -- | 0.83 | -- | 0.97 * |
| Testing per-Session, per-Method | -- | 0.97 | 0.08 | 0.01 * |
| Sequence of testing | -- | 0.74 | -0.06 | 0.03 * |

Fixed effects $R^2$ = 5%

Fixed effects $R^2$ = 10%