SCIENCE
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Real-World Study of the Security of Educational Test Systems

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OSVS 2025

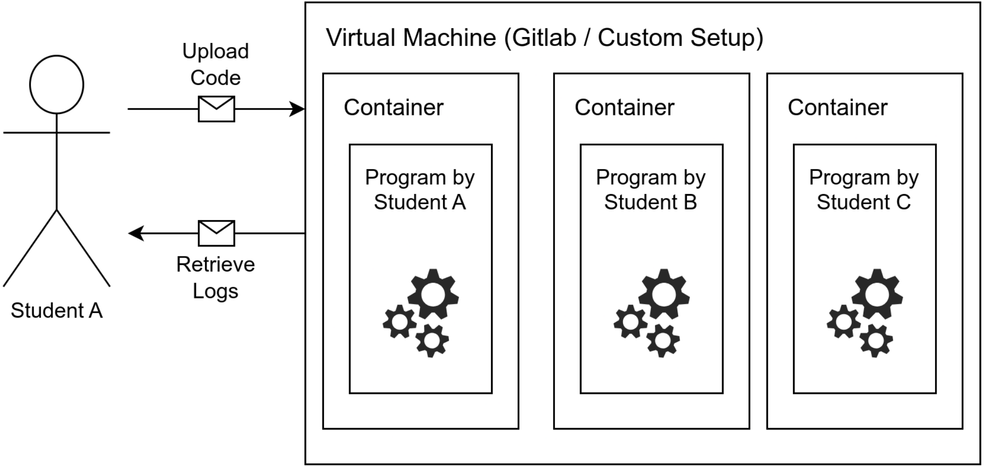
Educational Test Systems

Do you teach programming?

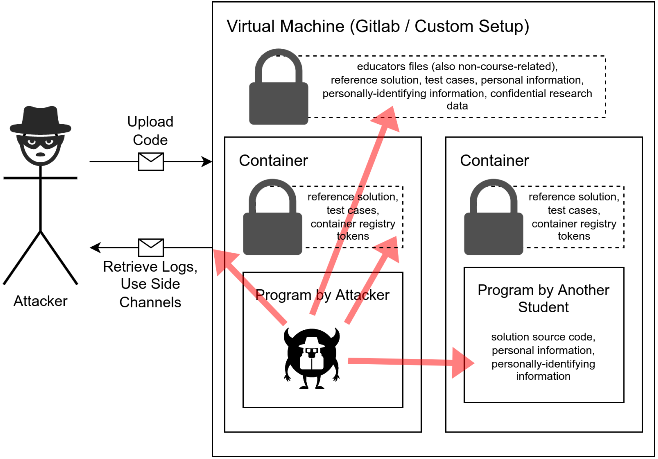

EXAM
EXAM
EXAM
EXAM
EXAM
EXAM

Do you use a test system for grading?

Test System Setup



Threat Model



Analyzed Test Systems

System	Educational Context	Languages	User Interface	Students
GD1	Introductory	C	Git	770
GD2	Introductory	C	Git	366
GD3	Introductory	C++	Git	547
C4	Systems	C, C++, Assembly	Git, Web	134
GD5	Formal Methods	Python	Git	125
GD6	Privacy	C++, Python	Git	57
GC7	Software Development	Java	Git	413
C8	Systems	C++	-	547
GD9	Security	Python	Git	413
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GD: GitLab Runners with Docker, **GC:** GitLab Runners with custom pipeline, **C:** fully custom

Methodology

Asset-oriented Security Evaluation

Primary Interest Assets

- private test cases
- reference solutions
- other students' solutions
- other students' scores

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- credentials / access tokens
- code execution as root
- container escape

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← Intermediate Step

Secondary Interest Assets

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Continuous Integration for the Attacker

Benign students...

Attackers...

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- get feedback about their solutions quickly

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Continuous Integration for the Attacker

Benign students...

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Attackers...

- get feedback about their exploits quickly
- can exfiltrate secrets via log file

What if attackers cannot write to the log file?

- use other pipeline artifacts (if possible)

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For every secret byte `b` do:

```
sleep(b);
```

Categorization of Security Issues

Output Sanitation

Permissions

Misconfiguration

Environment Sanitation

Categorization of Security Issues

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- failure to block attempts to output sensitive information
- hard due to arbitrary encodings, side channels

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- failure to block access to sensitive resources
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Misconfiguration

- e.g. unfiltered Internet access, outdated software, unprotected access tokens

Environment Sanitation

- failure to protect build/test environment
- e.g. `Makefile`, `.gitlab-ci.yml`

Results

Mitigated ✓ and Unmitigated ✗ Attack Vectors

Security Issue	GD1	GD2	GD3	C4	GD5	GD6	GC7	C8	GD9	C10	C11
Unsanitized Output	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓
Timing Side Channels	✗	✗	✗	?	✗	✗	?	?	✗	?	?

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Timing Side Channels	✗	✗	✗	?	✗	✗	?	?	✗	?	?
No Container	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓
Privileged Git Tokens	✗	✗	✗	✓	✓	✓	✓	✗	✓	✓	✓
Reference Solution	✗	✗	✗	✓	✗	✓	✓	✗	✓	✓	✓
Exec as Root	✓	✓	✓	✓	✗	✓	✓	✓	✓	✗	✗

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Exec as Root	✓	✓	✓	✓	✗	✓	✓	✓	✓	✗	✗
`DOCKER_AUTH_CONFIG`	✗	✗	✗	✓	✗	✗	✓	✓	✗	✓	✓
`ptrace`	✓	✓	✓	✗	✗	✗	?	✗	✓	✗	✓
Internet Access	✗	?	?	✗	✓	✓	✗	✗	✓	✓	✓
Outdated Software	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓
Docker Socket Mount	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓

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No Container	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓
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`DOCKER_AUTH_CONFIG`	✗	✗	✗	✓	✗	✗	✓	✓	✗	✓	✓
`ptrace`	✓	✓	✓	✗	✗	✗	?	✗	✓	✗	✓
Internet Access	✗	?	?	✗	✓	✓	✗	✗	✓	✓	✓
Outdated Software	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓
Docker Socket Mount	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓
Modify Pipeline	✗	✗	✗	✓	✓	✓	✗	✓	✓	✓	✓
Build System Takeover	✗	✗	✗	✗	✓	?	✓	✓	✓	✓	✓

Summary

Out of 11 test systems:

- 6 without output sanitization

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- 6 without output sanitization
- 6 exposed container registry credentials to student code via `DOCKER_AUTH_CONFIG`
- 5 exposed reference solutions to the attacker
- 4 allowed to manipulate the pipeline configuration
- 5 with writable Makefiles or build scripts

Case Study GD5

Properties

Educational Context:	formal methods
Architecture:	GitLab runners + private Docker registry
Primary Assets:	test cases, reference solution
Students:	125

Case Study GD5: Findings (1/2)

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Output Sanitiation

- no sanitation
- auth. token leakable within 156 s to 1820 s via timing side channel

Case Study GD5: Findings (1/2)

Output Sanitation

- no sanitation
- auth. token leakable within 156 s to 1820 s via timing side channel

Permissions

- reference solution in container
- private testcases in container
- student code executed as root in container

Case Study GD5: Findings (2/2)

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Misconfiguration

- code can `ptrace` parent process to access test cases
- `DOCKER_AUTH_CONFIG` exposed to student code

Case Study GD5: Findings (2/2)

Misconfiguration

- code can `ptrace` parent process to access test cases
- `DOCKER_AUTH_CONFIG` exposed to student code

Environment Sanitation

- no issues found

Case Study GD1

Properties

Educational Context:	introductory
Architecture:	GitLab runners + private Docker registry
Primary Assets:	private test cases, reference solution
Students:	770

Case Study GD1: Findings (1/2)

Case Study GD1: Findings (1/2)

Output Sanitation

- no sanitation
- auth. token leakable, live reports on test-case run times

Case Study GD1: Findings (1/2)

Output Sanitation

- no sanitation
- auth. token leakable, live reports on test-case run times

Permissions

- API token for private test case repo accessible
- test case repo also contains reference solution

Case Study GD1: Findings (2/2)

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Misconfiguration

- `DOCKER_AUTH_CONFIG` exposed to student code
- outbound connections allowed when fetching test cases

Case Study GD1: Findings (2/2)

Misconfiguration

- `DOCKER_AUTH_CONFIG` exposed to student code
- outbound connections allowed when fetching test cases

Environment Sanitation

- `.gitlab-ci.yml` overwritable by students
- `Makefile` overwritable by students

Case Study C4

Properties

Educational Context:	Systems
Architecture:	custom (build in chroot, execute in Qemu fork)
Primary Assets:	private test Cases, other students' solutions
Students:	134

Case Study C4: Findings (1/2)

Case Study C4: Findings (1/2)

Output Sanitation

- some sanitation, but not during build and startup
- test cases leakable

Case Study C4: Findings (1/2)

Output Sanitation

- some sanitation, but not during build and startup
- test cases leakable

Permissions

- no issues found

Case Study C4: Findings (2/2)

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Misconfiguration

- outbound connections allowed during all pipeline phases
- Qemu fork outdated and unpatched against escape vulnerabilities
- software within `chroot` outdated (escape possible via `sudo`)
- same user account for all pipelines of different students
- `ptrace` across different processes not prohibited

Case Study C4: Findings (2/2)

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- software within `chroot` outdated (escape possible via `sudo`)
- same user account for all pipelines of different students
- `ptrace` across different processes not prohibited

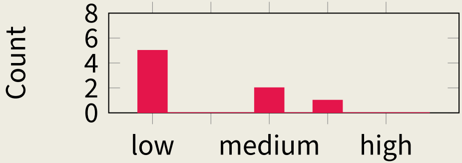
Environment Sanitation

- `Makefile` overwritable by students
- helper programs overwritable

User Study

How Do Test System Maintainers Assess The Severity?

Reading Solutions of Others



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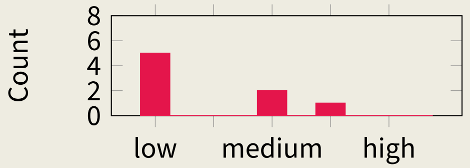
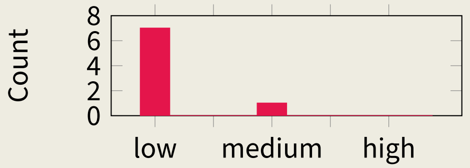


Writing Solutions of Others



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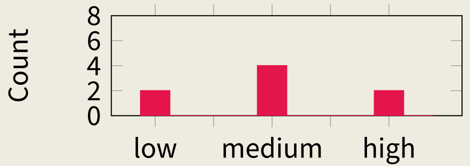

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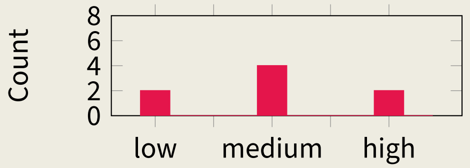
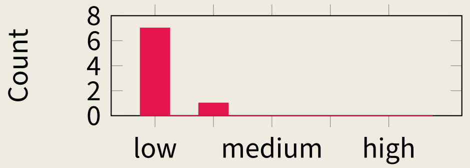
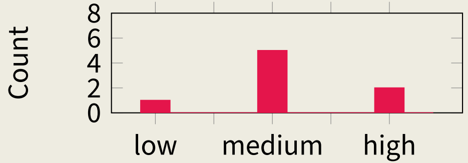


Writing Test Cases



How Do Test System Maintainers Assess The Severity?

Reading All Test Container Files



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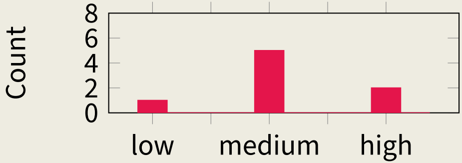
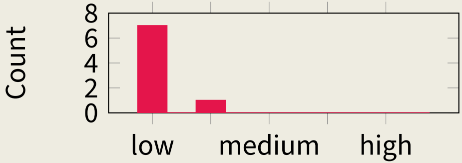
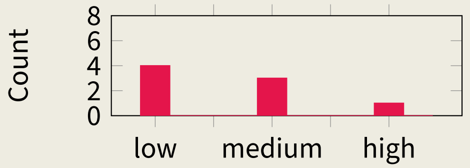


Writing All Test Container Files



How Do Test System Maintainers Assess The Severity?

Reading Container Registry



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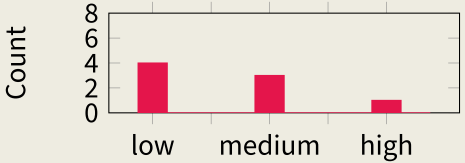

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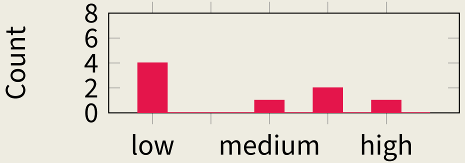
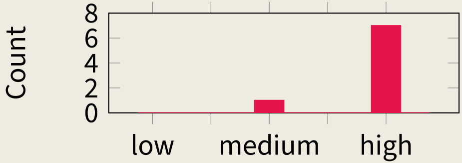


How Do Test System Maintainers Assess The Severity?

Reading Container Host



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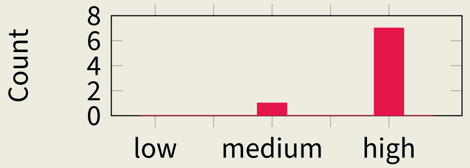
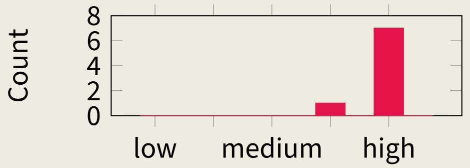


Writing Container Host



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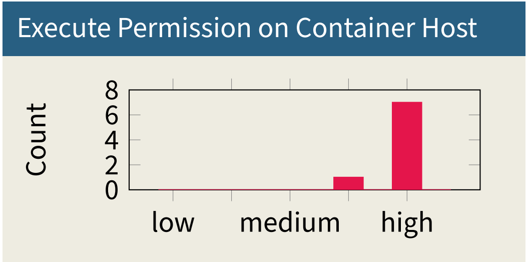

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Google

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