

Pedalogical

AI-Grounded Vulnerability Feedback for Non-Security CS Courses

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This talk presents the Pedalogical project, a web-based platform that provides AI-generated vulnerability feedback for non-security CS courses.

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1 TL;DR

1.1 *We propose a new tool and pedagogical approach to improve cybersecurity education.*

2 Problem & Motivation

2.1 We Need to Improve Education in Developing Secure Code

Security failures start early.

Students often learn to write code before they learn to write *secure* code.

- Software vulnerability exploitation remains a leading vector in breaches; secure coding must be integrated early [1], [2], [3].
 - Teaching students to use static analyzers early is important, but is very difficult due to the complexity of the output of these tools.
 - Existing static analyzers flag issues but rarely deliver **actionable, level-appropriate pedagogy** [4], [5].
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2.2 Prior Findings: What We Know So Far

Empirical evidence supports this gap.

- Vulnerabilities **increase and diversify** as students progress from CS1 → advanced courses [6].
- Many CS programs lack sustained, program-wide security practice; students introduce vulnerabilities in routine coursework [6], [7], [8].
- Mismatch between vulnerabilities students actually produce and those emphasized in detection research [8], [9].
- Time pressure & functionality-first norms drive insecure patterns; targeted feedback can help [7], [9].

2.3 Research Gap

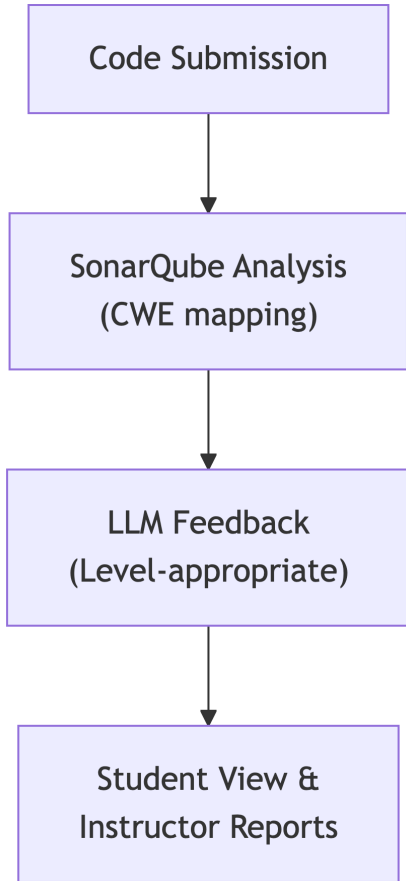
- Need an **evidence-based, scalable mechanism** that:
 - Grounds detection in a **truthful analyzer** [4]
 - **Adapts feedback** to student level (beginner → advanced) [10]
 - Supports **longitudinal study** across multiple courses/institutions
 - Collects telemetry for **learning analytics**

3 Proposed Approach

3.1 Pedalogical

- **Pedalogical** = Static Analysis (truth base) + LLM (tailored feedback)
 - Analyzer: SonarQube CE (CWE mapping) → issues & hotspots [4]
 - LLM: transforms findings into **scaffolded, actionable guidance** (tailored levels) [10]

3.2 System Pipeline



Grounded analyzer reduces hallucination risk; LLM provides audience-appropriate feedback.

3.3 Pedagogical Learning Theories

- Integrates proven learning theories into the system design to enhance the learning experience:
 - **Cognitive Load Theory** [10]: convert verbose analyzer output → concise, relevant guidance (reduce extraneous load).
 - **Zone of Proximal Development** [11]: feedback level aligned to course maturity (scaffolding).

3.4 Pedalogical Application

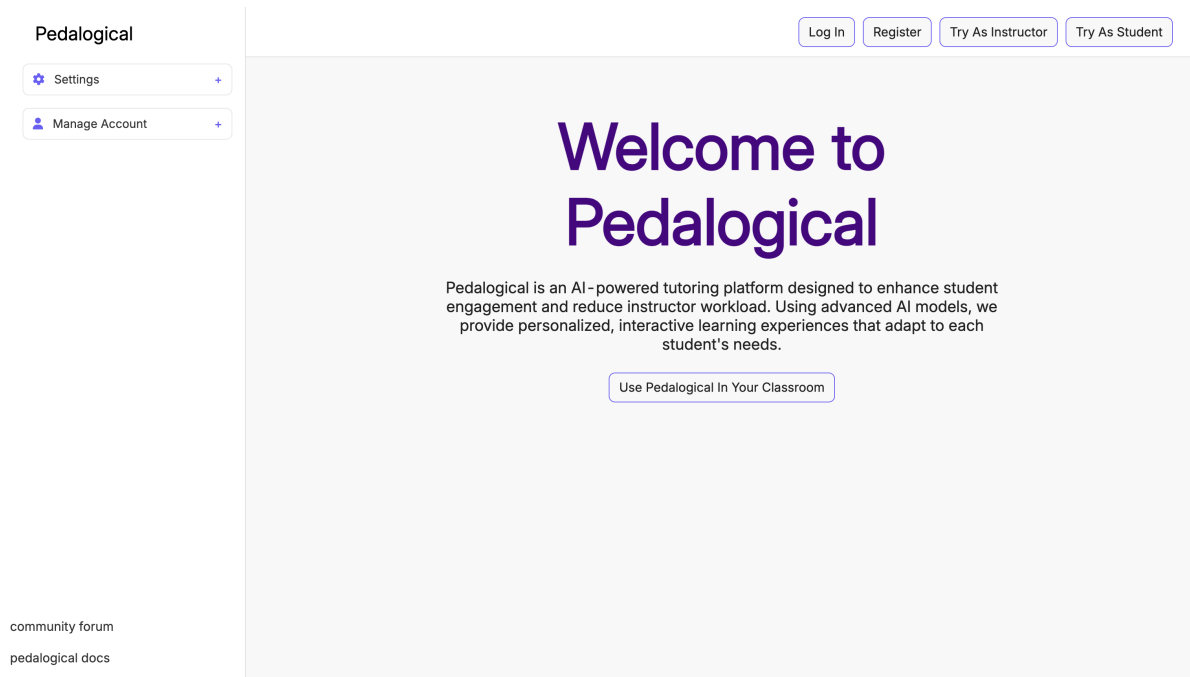


Figure 1: Figure: Pedalogical Application

3.5 Pedalogical Question Nodes

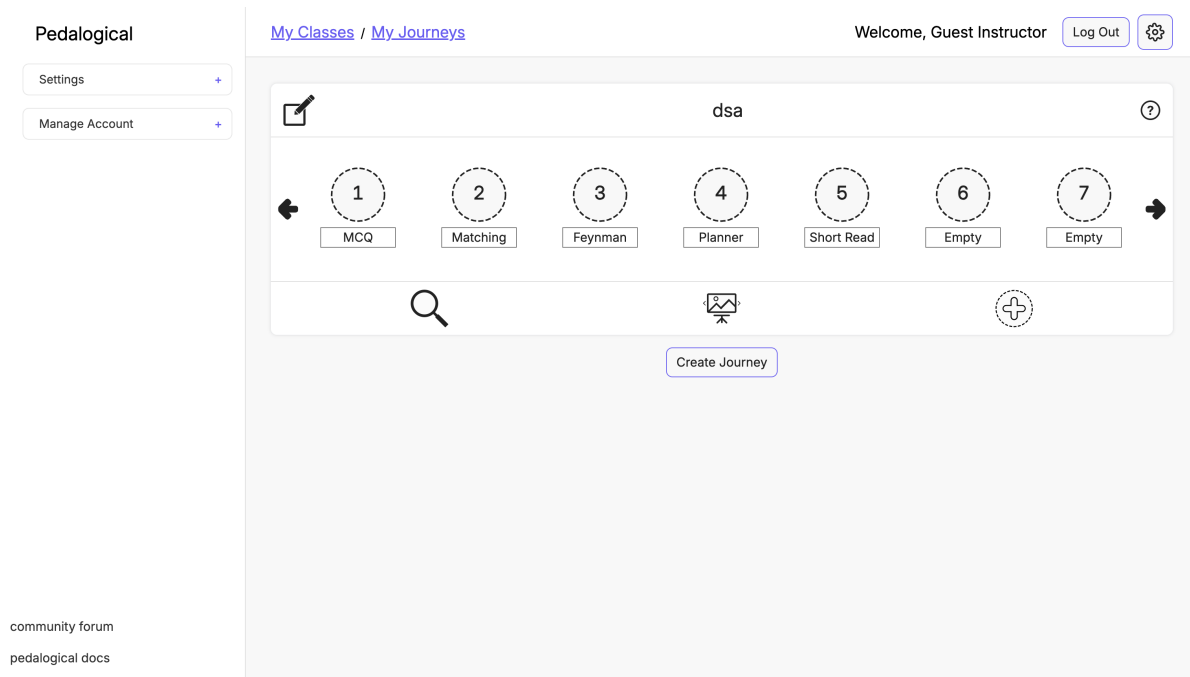


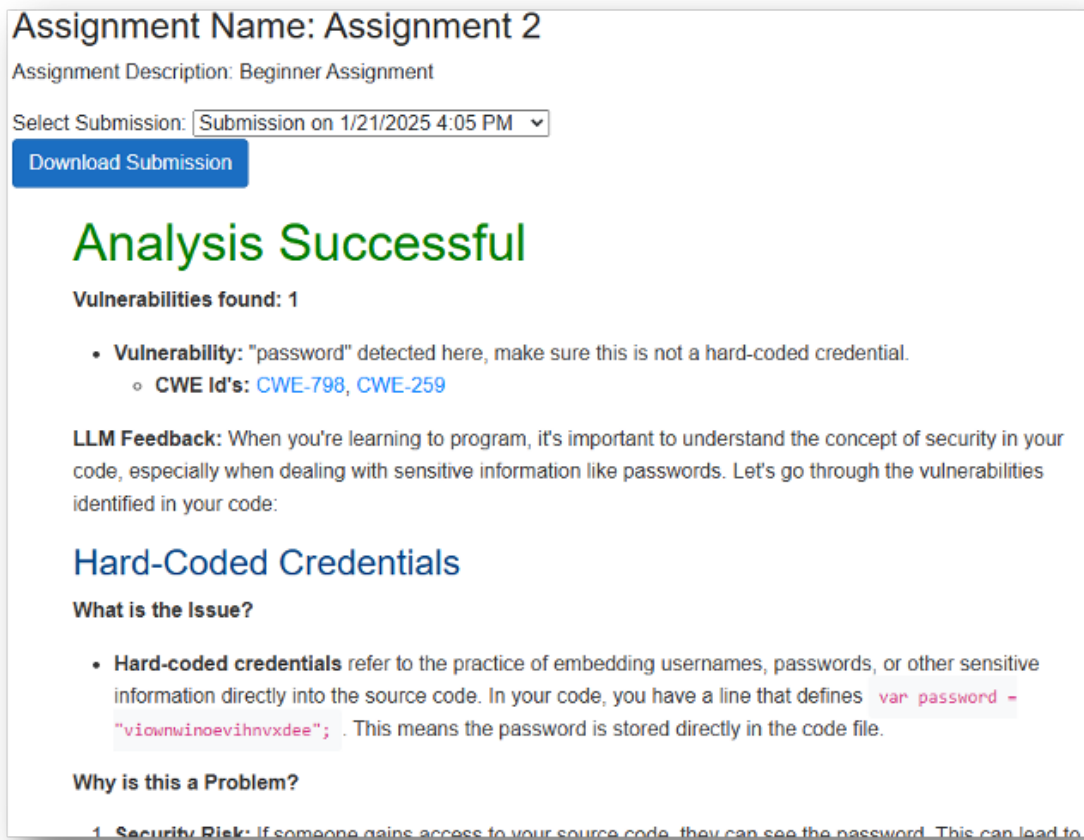
Figure 2: Figure: Pedalogical Question Nodes

3.6 Pedalogical LLM Question Generation

The screenshot displays the Pedalogical LLM Question Generation interface. On the left, a sidebar contains 'Settings' and 'Manage Account' with plus icons. The main header shows 'Pedalogical' and navigation links for 'My Classes' and 'My Journeys'. The top right corner includes a welcome message 'Welcome, Guest Instructor', a 'Log Out' button, and a settings gear icon. The central modal window is titled 'Learning Outcome' and contains a text input field with 'Basic Cyber Security Intro Class Question'. Below this, the 'Question Type' is set to 'Multiple Choice'. The 'Question Prompt' field contains the text 'What is the primary purpose of antivirus software in cyber security?'. The 'Answers' section lists four options: 'To detect, prevent, and remove malware' (highlighted in green), 'To monitor network traffic', 'To manage user passwords', and 'To enhance website performance'. At the bottom of the modal are two circular buttons: a red one with a white 'X' and a green one with a white checkmark. The background interface shows a 'community forum' and 'pedagogical docs' link at the bottom left, and a sequence of steps (6, 7) with 'Empty' labels and a plus icon on the right.

Figure 3: Figure: Pedalogical LLM Question Generation

3.7 Cybersecurity: Sample Student Feedback



The screenshot displays a web interface for a cybersecurity assignment. At the top, it shows the 'Assignment Name: Assignment 2' and 'Assignment Description: Beginner Assignment'. Below this is a 'Select Submission' dropdown menu showing 'Submission on 1/21/2025 4:05 PM' and a blue 'Download Submission' button. The main heading is 'Analysis Successful' in green. Underneath, it states 'Vulnerabilities found: 1' and lists a vulnerability: 'Vulnerability: "password" detected here, make sure this is not a hard-coded credential.' with associated CWE IDs 'CWE-798, CWE-259'. An 'LLM Feedback' section explains the importance of security and mentions vulnerabilities identified in the code. A section titled 'Hard-Coded Credentials' asks 'What is the Issue?' and lists that 'Hard-coded credentials' refer to embedding sensitive information directly into source code, citing a specific line of code: `var password = "viownwinoevihnvxdee";`. Another section titled 'Why is this a Problem?' lists a 'Security Risk' where access to source code could reveal the password.

Assignment Name: Assignment 2

Assignment Description: Beginner Assignment

Select Submission: Submission on 1/21/2025 4:05 PM

Download Submission

Analysis Successful

Vulnerabilities found: 1

- **Vulnerability:** "password" detected here, make sure this is not a hard-coded credential.
 - **CWE Id's:** [CWE-798](#), [CWE-259](#)

LLM Feedback: When you're learning to program, it's important to understand the concept of security in your code, especially when dealing with sensitive information like passwords. Let's go through the vulnerabilities identified in your code:

Hard-Coded Credentials

What is the Issue?

- **Hard-coded credentials** refer to the practice of embedding usernames, passwords, or other sensitive information directly into the source code. In your code, you have a line that defines `var password = "viownwinoevihnvxdee";`. This means the password is stored directly in the code file.

Why is this a Problem?

1. **Security Risk:** If someone gains access to your source code, they can see the password. This can lead to

Figure 4: Figure: Sample Student Feedback

3.8 What Instructors Get

- Cohort dashboard: per-assignment vulnerability counts & trends.
- Downloadable reports: analyzer findings, prompts/responses, submission diffs.
- Configurable **feedback detail level** for scaffolding.

3.9 Sample Instructor Report

Assignment 3								
Intermediate								
	Total	Latest	Vulnerabilities	Latest Submission Filesize (KB)	Total Time Spent	Average Time Spent	Total Time Spent	Average Time Spent
					Viewing LLM Feedback (Seconds)	Viewing LLM Feedback (Seconds)	Unsuccessful Build Feedback (Seconds)	Unsuccessful Build Feedback (Seconds)
Andrew Sanders	5	01/21/2025 02:56:50	0	0.19	N/A	N/A	62	31
Bandrew Banders	1	01/21/2025 00:50:36	1	0.30	50	50	N/A	N/A
Download report with latest submissions					Download report with all submissions			

Figure 5: Figure: Sample Instructor Report

4 Proposed Study Context

4.1 Research Questions

RQ1: Is AI-generated vulnerability feedback associated with **reduced vulnerabilities** in revised submissions?

RQ2: Does exposure to AI-generated vulnerability feedback **improve secure coding practices** over time?

4.2 Proposed Study Context

- Multi-course, multi-institutional.
- Undergraduate courses (intro → advanced; multiple sections; in-person & online).
- Incentivized via **bonus points** contingent on meeting minimum functionality and reducing vulnerabilities.

4.3 Data & Measures

- **Static analysis artifacts:** CWE-tagged vulnerabilities, security hotspots, bugs, code smells.
- **Engagement telemetry:** time on feedback, resubmission frequency, interaction with explanations.
- **Learning signals:** pre/post patterns across assignments; regression models of engagement → reduction.
- **Qualitative:** end-of-semester survey on usefulness & strategies.

4.4 Analysis Plan

- Longitudinal within-course and cross-course comparisons.
- Regression modeling: engagement metrics → vulnerability change.
- Category-level success: which CWE types improve most?
- Sensitivity to bonus-point variability across courses (limitations acknowledged).

4.5 Expected Contributions

- A **replicable pipeline** for secure-coding feedback integrated into non-security courses.
- Evidence that **grounded LLM feedback** can reduce vulnerabilities and shape habits .
- A platform for **program-level learning analytics** on secure coding.

4.6 Anticipated Threats & Limitations

- Bonus-point schemes differ across courses → potential confounds.
- Structured prompts mitigate LLM variability, but do not eliminate it [12].

5 Encouraging Early Analysis

5.1 Pedalogical in a CS2 (Data Structures) Course

- Students designed and selected data structures for a medium-sized programming project.
- Experimental group used the Pedalogical chatbot for guided reasoning and scaffolding, while the control group used a generic ChatGPT-4.0 wrapper, enabling comparison of design quality, reasoning depth, and tool engagement.
- Students in the experimental group performed significantly better on project outcomes, suggesting increased metacognitive awareness and problem-solving strategies based on rubric-based grading.

5.2 Call to Action

- Adopt Pedalogical in non-security courses to **normalize secure coding**.
- Collaborate on **cross-institutional studies** and shared analytics.
- Extend to additional languages & rulesets; explore adaptive feedback policies.

6 Thank You!

6.1 Contact Information

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