

ThermalQuest

Gamifying Thermal Side-Channel Attack Education with Interactive Pipeline and Memory Visualization

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MOTIVATION

- Thermal side-channel attacks are difficult for beginners to understand because the leakage is indirect and usually, invisible
- Existing educational cybersecurity games usually focus on more common attacks like phishing, code injection or they are made to be competitive like CTF- style challenges
- Students or beginners need a beginner-friendly, hands-on way to connect system activity with observable thermal leakage

GOAL

To develop and evaluate a beginner-friendly educational game that uses visual heat feedback to teach thermal-side channel attack concepts.

RESEARCH GAP / LITERATURE REVIEW

There exist:

- Advanced side-channel attack research (ThermalBleed, ARCHER)
- Cybersecurity gamification tools on common attacks like phishing or web security (SecureArcade, picoCTF etc)
- But lack of beginner friendly educational games on thermal side-channel attacks

Current tools lack:

- Visual feedback and simplified interaction
- Easy accessibility
- Guided learning

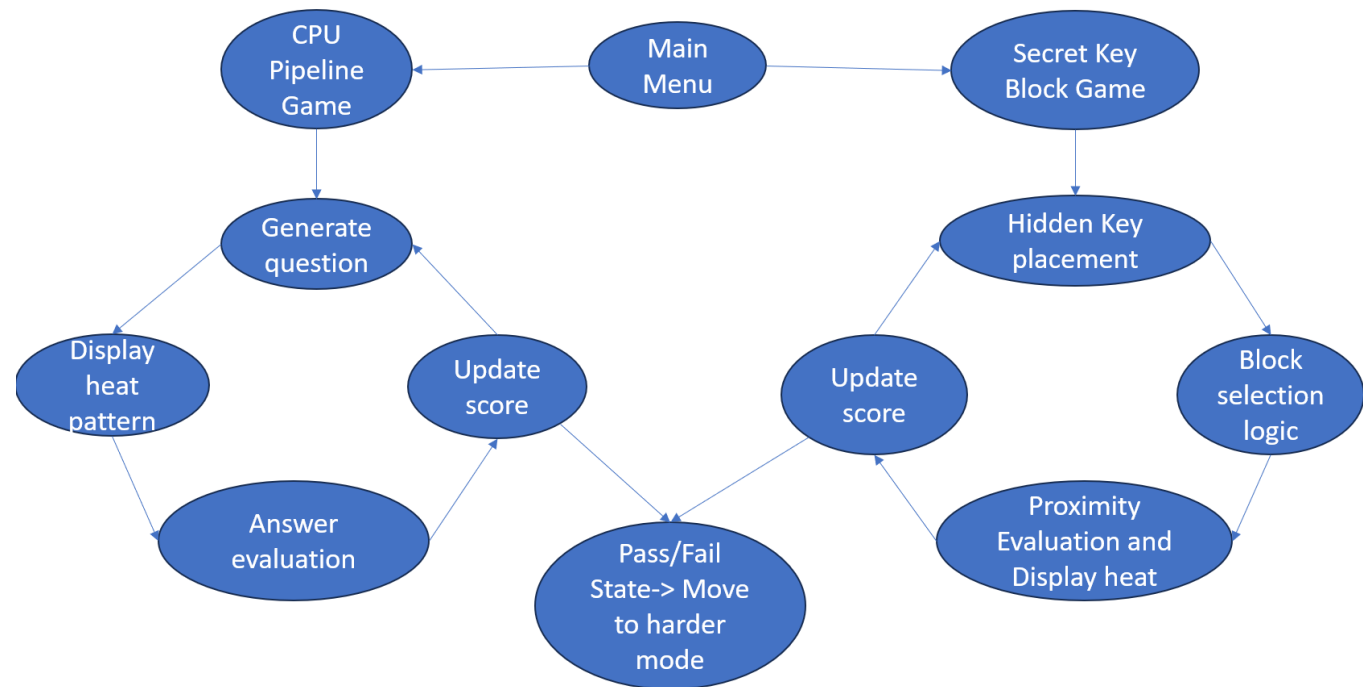


EXPERIMENT

- To design and develop an educational WebGL game project on thermal side-channel attacks called ThermalQuest
- It contains 2 different learning games:
 1. CPU Pipeline Heat game
 2. Hidden-key Heatmap game
- To evaluate whether students found it understandable, engaging and useful

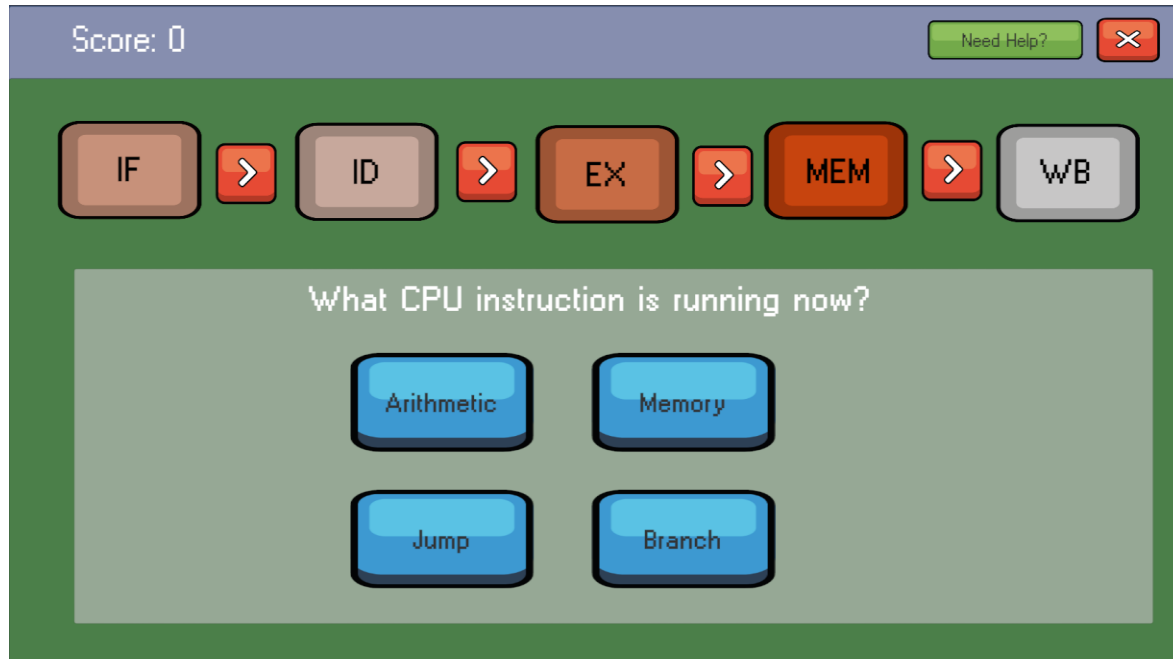
GAME CONTROL FLOW

- The two game modules are built with Unity's UI and script features
- The scripts are written on C# which control the following:
 - Questions
 - Heat patterns
 - Scoring
 - Hints
 - Timers
 - Scene transitions

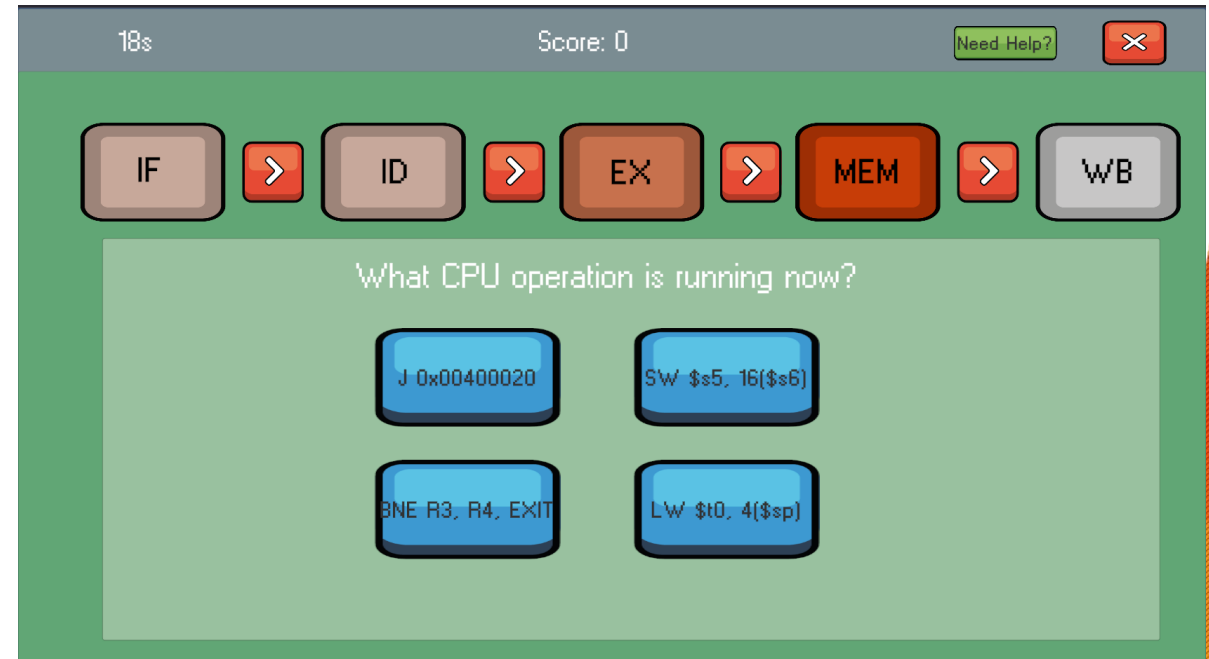


GAME 1: CPU PIPELINE HEAT GAME

- Different CPU operations produce different heat activity patterns across pipeline stages
- Students observe the stages IF, ID, EX, MEM, and WB, interpret the heat pattern shown and then, identify what instruction is running.



Easy Mode: Instruction categories are provided



Hard Mode: Specific instructions, under a timer

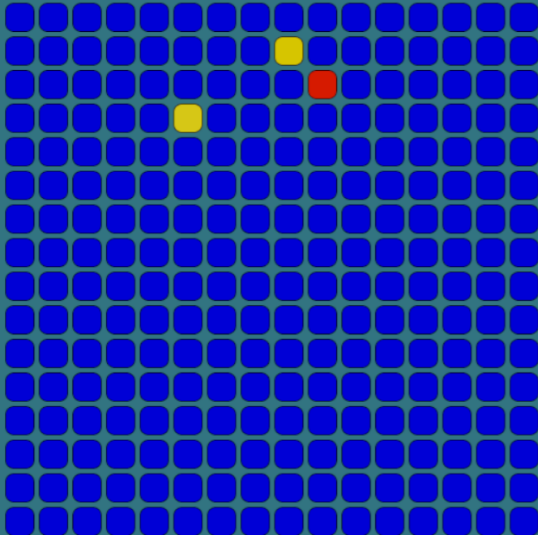
GAME 2: HIDDEN KEY HEATMAP GAME

- This game is focused on thermal access over memory access patterns and partially inspired by memory/cache side-channel concepts
- Players search for a hidden key placed in a 256-block memory grid
- Heat feedback in the heatmap grid indicates how close the selection of blocks is to the target block containing the key
- Easy Mode includes limited hints to support the search process
- Hard Mode provides no hints and has a timer

HIDDEN KEY HEATMAP GAME

Score: 201 Attempts Left: 1 Hints Left: 1

[Hint?](#) [Need Help?](#) [X](#)



Very hot!

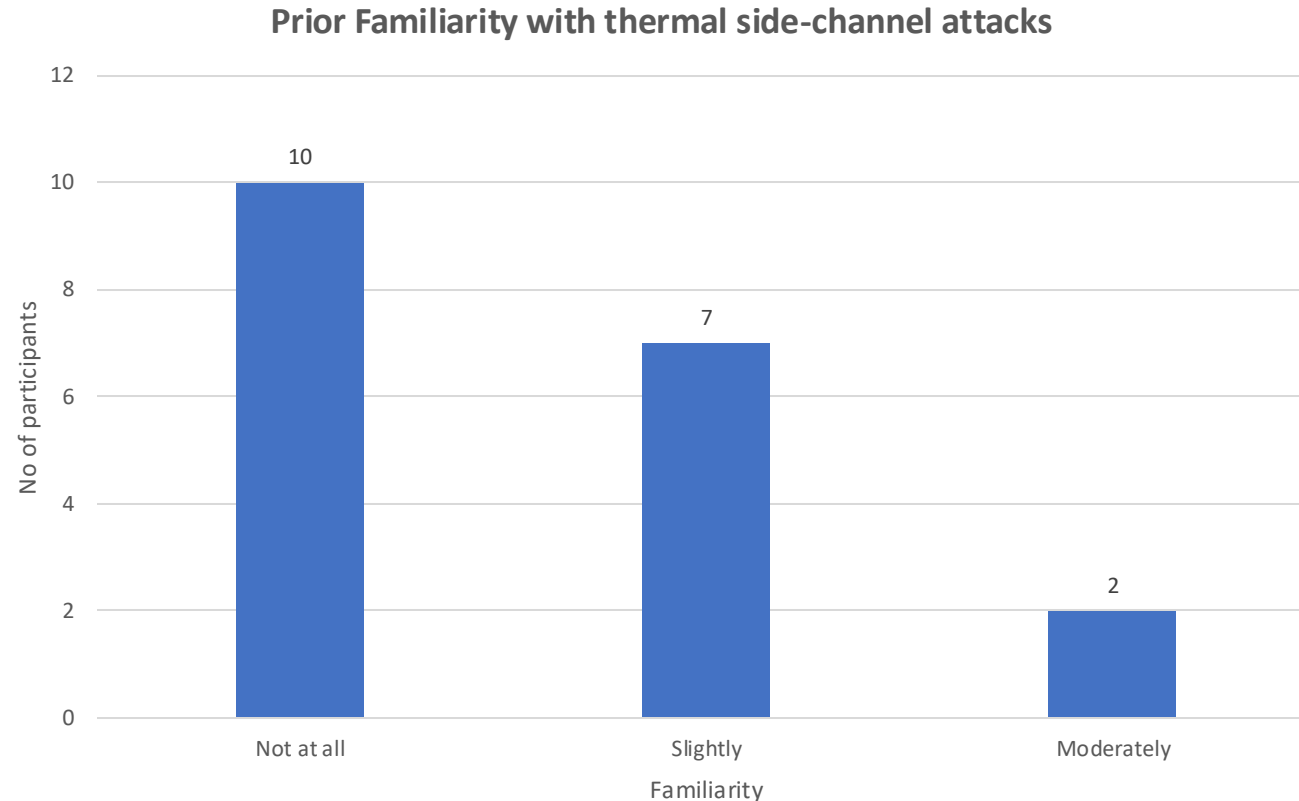
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[Test for Heat](#)

EVALUATION SETUP

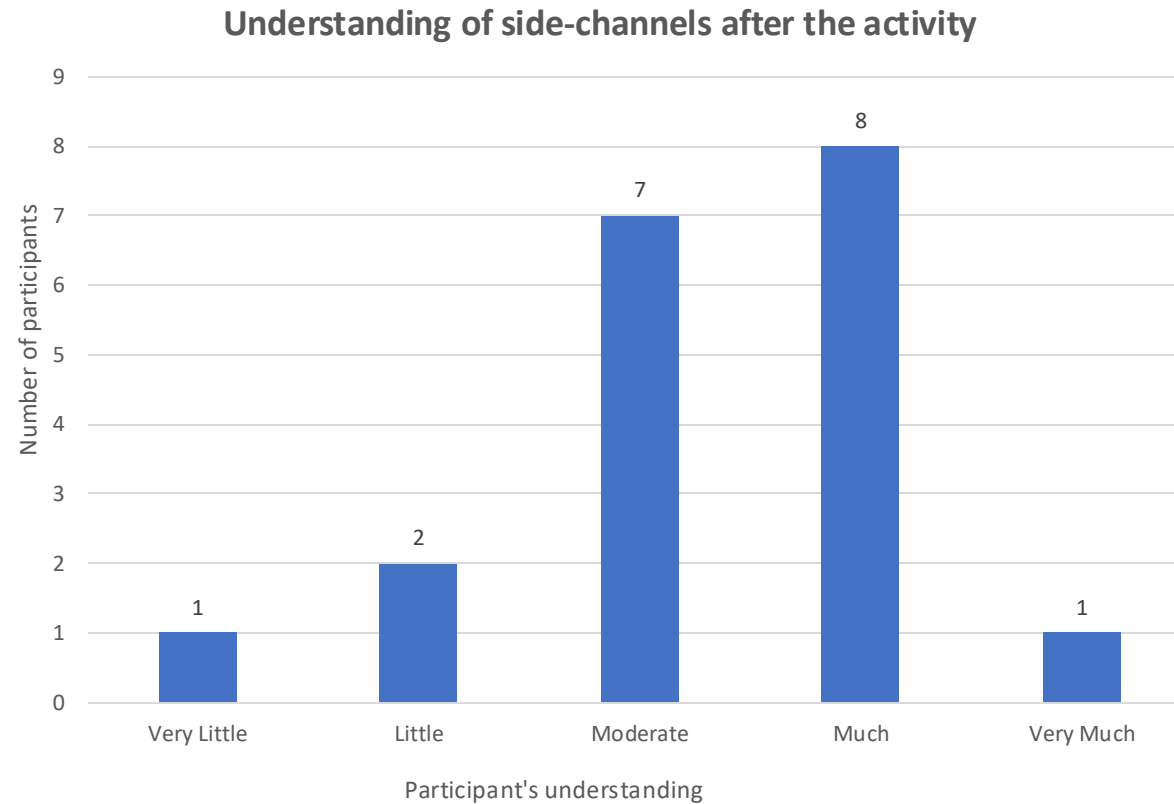
- Classroom activity was performed with Computer Science students
- 22 students attended, out of which 19 completed the survey
- Students played the game via a Vercel link provided by the presenter
- Survey measures:
 - Prior familiarity with thermal side-channels
 - Usability of game
 - Engagement of game
 - Visual feedback
 - Perceived learning
 - Comparison with lecture-based learning
 - And a few other game related questions like difficulty, technical difficulties, etc

PRIOR FAMILIARITY WITH THERMAL SIDE-CHANNEL ATTACKS



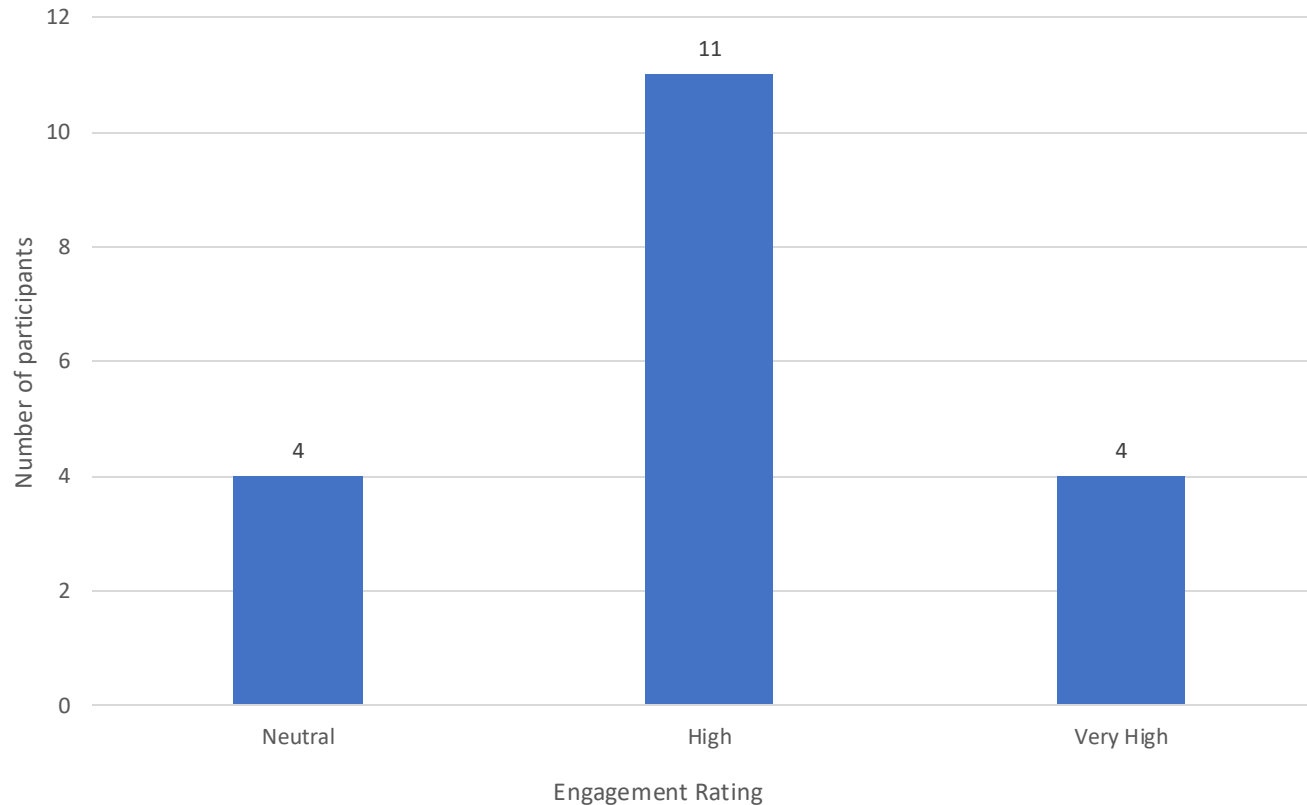
- Most students came in with no or low familiarity of side-channel concepts with an overall average of 1.58 out of 5
- Most students reported that they were either not familiar with the concept or they were only slightly familiar with the concept

UNDERSTANDING OF SIDE-CHANNEL ATTACKS POST ACTIVITY



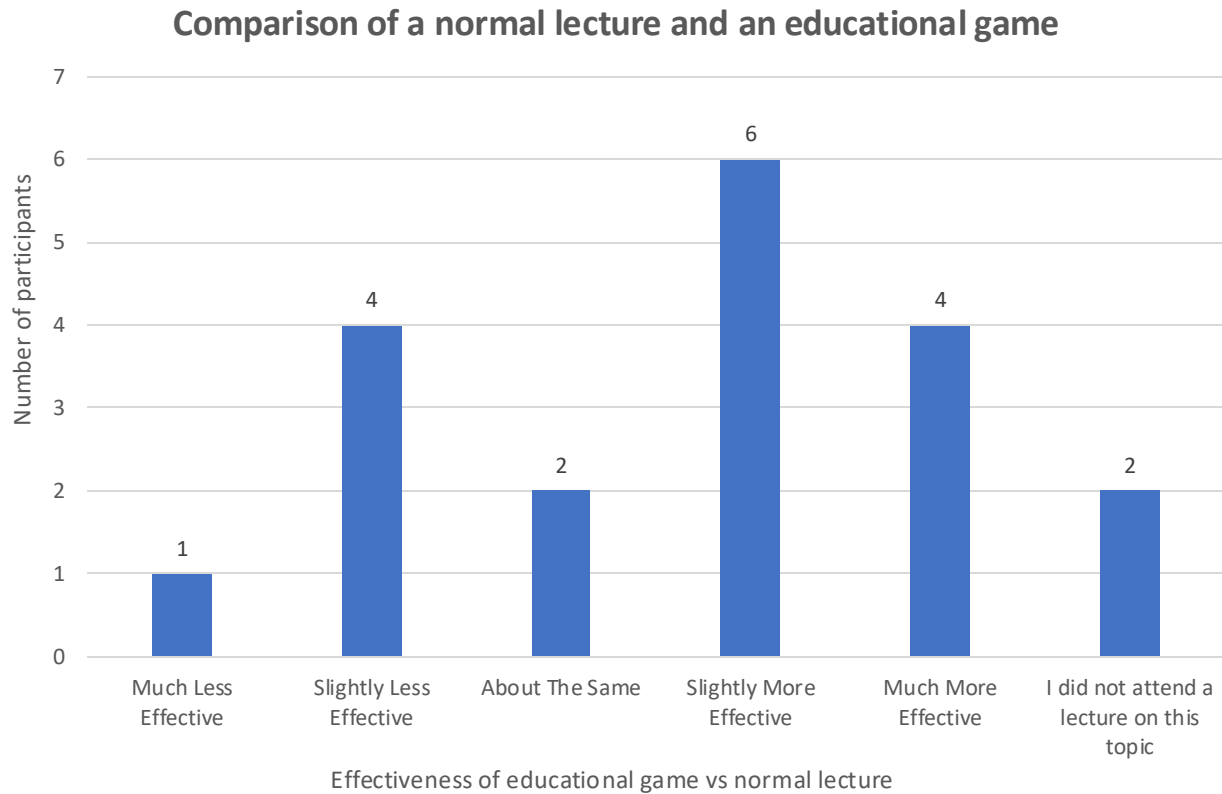
- Most students understood the concept of side-channel attacks, with the majority reporting moderate or much understanding
- The average score was 3.31/5

ENGAGEMENT OF THE GAME



- The game has been perceived to be very engaging, with an average score of 4.0/5
- Most ratings were clustered at the top
- This supports the notion that the game sustains interest

EFFECTIVENESS OF THE GAME COMPARED TO A LECTURE



- The game has been perceived to be moderately effective, with most students voting slightly more effective and much more effective
- The average score is 3.47/5

DISCUSSION

- The evaluation of this project was done in one class, small survey sample($n=19$, one class) - the original plan included a second non-CS class (Business) for comparison, but we were unable to do it due to time constraints
- Occasional technical issues
- Some students still didn't understand how the gameplay was connected to real-world attacks

POINTS OF IMPROVEMENT

- Adding better onboarding for new players
- Adding more side-channel types such as:
 - Cache timing
 - Power analysis
 - Branch prediction
 - Speculative execution
- Conducting larger evaluation with different major groups
- Adding more realistic attack models

CONCLUSION

- The project bridges advanced side-channel research and beginner-level learning
- Survey results show improved perceived understanding and positive engagement
- The game works best as an introductory tool and a supplement to lectures, not a replacement for advanced labs or simulators