ISSN: 2473-4901
v12 n6717

CTF Design In Cybersecurity Education: Overcoming Technology Friction

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Abstract

Capture the Flag (CTF) competitions are commonly used in cybersecurity education. Participants apply previously acquired skills in a time-constrained situation with known answers. Though valuable for assessment, CTF competitions do not address the broader range of skills needed for success as a cybersecurity professional e.g., anticipatory thinking, critical thinking, and soft skills. Formulating CTF challenges requires a much higher level of understanding than just solving the challenge, and is traditionally done by educators. The process of designing games stimulates critical and anticipatory thinking in designers. Constructing realistic "wrong" paths can deepen knowledge and stimulate further cybersecurity skill development as well as critical thinking. This research explores broadening skill development in cybersecurity design and defense by participating in CTF design. The primary objective is for CTF participants to successfully create challenges as a way to develop a broader and more strategic problem-solving skill set. The secondary objective is to assess if game building is as enjoyable as game participation. Identifying a model that accurately describes what blocks successful design by students is key to these objectives.

Keywords: Capture the flag, cybersecurity education, gamification, experiential learning, technology fatigue

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1. INTRODUCTION

Cybersecurity educators have focused on preparing for and embedding the content of industry certifications in their curriculum (Erickson & Kim, 2021). This, however, is not the only skill area that business leaders look for in future cybersecurity professionals. Equally important are soft skills of communication and collaboration. Project-based learning combines those added elements with technical skills by requiring a balance between imaginative and analytical thinking (Fiteriani et al., 2021).

Capture the Flag (CTF) contests are popular tool for cybersecurity education (Nagare et al., 2025). Improving perceived usefulness of CTF leads to more likely adoption per the Technology Acceptance Model (Granić & Marangunić, 2019). This research focuses on designing the CTF contest. Instead of just solving challenges, the participants must also create a challenge and analyze how to defend the challenge. Designing games stimulates critical thinking by requiring designers to identify problems, evaluate alternate solutions, and iteratively refine their designs (Ruggiero & Watson, 2014). Empirical research further suggests that engaging learners in digital game authorship can improve critical-thinking skills (Yang & Chang, 2013).

Gamification is being used to combat security compliance fatigue in a broader context than just formal university education. Research on cybersecurity training further suggests that combining live activities such as CTFs with traditional instruction can improve training outcomes (Workman, 2021). However, traditional CTFs tend to emphasize technical skills, suggesting that workplace awareness CTFs should incorporate nontechnical challenges that reflect the security decisions employees encounter in their daily work (Švábenský et al., 2018).

If workplaces are using CTF games, then CTF design competence is also a relevant work-skill for a student. Experiential learning is the gold standard for multiple disciplines (Clark & White, 2010), particularly in business. Though noted for increasing problem-solving ability, this technique has not been emphasized in learning for Science, Technology, Engineering, and Mathematics (STEM) disciplines (Lestari, 2021). This gap seems contradictory in fields where problem-solving is the focus.

Though CTF design is not inherently a game, the exercise must still be enjoyable to reap the retention and positive attitude benefits similar to gameplay. Supporting the designers through the process and eliminating cognitive load irrelevant to desired outcome enhances this outcome (Yang & Chang, 2013). Visual progress of completed tasks, similar to game leaderboards, gives students a success experience that enhances enjoyment (Cutting et al., 2023).

2. RELEVANT RESEARCH

2.1 Gamification and Technology Fatigue

In 2009 the concept of a "compliance budget" was proposed to how much effort users are willing to invest in following compliance policies (Beautement et al., 2008). This phenomenon coupled with "technology fatigue" exacerbated by the Covid-19 pandemic (Al Mulhım, 2023) and the ever-present "security fatigue" which motivates end users to avoid/subvert security controls (Stanton et al., 2016) creates a significant challenge to overcome in cybersecurity awareness.

Gamification has evolved from an experimental technique to a primary strategy to compensate for this fatigue triad of compliance budget, technology fatigue, and security fatigue. Traditional education methods, such as lectures and quizzes, quickly consume the compliance budget. Awareness education that provides enjoyment, such as gamification, can reset the budget.

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More recently a 2025 study from Luxembourg established that gamified structures promote psychological empowerment and autonomous motivation**.** By designing experiences that appeal to competence development and individual autonomy, training transitions from an operational "tax" to an engaging, self-driven, and even "fun" activity (Chen et al., 2025). Another way to describe security fatigue is cognitive load. If the cognitive load for compliance/security is lowered, usability goes up (Shneiderman et al., 2016; Sweller, 1988). Tolerance/compliance/adherence to security protocols subsequently increases (Pramod, 2025).

To maintain a strong cybersecurity posture, awareness and education content must be intentionally selected, regularly delivered, and purposefully governed (Safaeipour et al., 2026). To reduce security fatigue, researchers triggered training based on risk, and supplied it via gamified micro-training. Study participants deemed low risk because of good security behaviors were not forced through generic training simply to check a box (ibid.). Evidence of the failure of traditional training in common issues like phishing (Rozema & Davis, 2025) makes a gamified and tailored approach more attractive and more effective.

2.2 Cybersecurity Education and Capture the Flag

Gamification in cybersecurity education is not confined to the CTF model. An extensive survey of gamification applications (GA) that have been documented through research studies shows the games range from simple quizzes and Jeopardy-style game boards to full CTF environments (Weitl-Harms et al., 2023). Some of the simpler games such as *Kahoot!* can be configured by students with custom content. Other games, such as *Anti-Phishing Phil,* deliver a single concept with a shorter timespan in the game.

Though CTF usage has trended toward students as consumers, there is increasing interest in students as designers of serious games (Švábenský et al., 2018). The student designer brings a more diverse mindset to game design (Horcher, 2021) which can increase cultural accessibility. The Digital Story Telling (DST) typical of CTF challenges involves creating stories using images and graphics, and the designer's personal interpretation (Yang & Wu, 2012). DST success depends on a clear story creation process and usable software to support the activities. DST has been shown to generate student interest and concentration, and comprehension of complex learning content.

2.3 Design of CTF environments

Outside the academic setting, game-based learning models have high acceptance when enjoyment is adopted as a design principle (Stylianos et al., 2019). The highest level of user acceptance is created when the learning is like playing (Ismailovic et al., 2012). Enjoyment or "fun" is not just a tool for acceptance, it leads to usability because fun reduces the cognitive load (Wiberg, 2003). "Funology" which combines fun and technology as a design technique (Blythe et al., 2004), finds the reverse is also true - usability leads to enjoyment.

Even though the CTF model is popular, implementing a CTF in cybersecurity education is not a simple exercise. Though the popularity of gamification is growing, resources to support game delivery are scarce, thus open source is a key option to support such sharing (Deterding et al., 2011). The open source environments by their nature have variable documentation, which makes implementing these environments resource-intensive (Kucek & Leitner, 2020).

Like a gun range provides a safe place to practice using a dangerous weapon, practicing cybersecurity weapons needs a safe environment or cyber range. Gamified cybersecurity environments are typically in conflict with production infrastructure (Stylianos et al., 2019). The simulation of hacking activities requires a complexity and separation of environments that complicates the organizational infrastructure (Švábenský et al., 2018).

To counter this resistance, cloud-based cyber ranges such as TryHackMe.com are popular (O'Grady, 2026). External cyber ranges also allow access to newer technologies such as Artificial Intelligence (AI) with minimal resource investment (Vevera et al., 2025). Miguel & Izal (2026) developed a CTF as a Service (CaaS) hosting platform that holds a Jeopardy-style game. All of these implementations show the complexity of an authentication system coordinating with scoring and leaderboards and a stable,

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isolated environment (Miguel & Izal, 2026) that participants are actively compromising as the goal of the exercise. The overhead and lack of administrative usability is a documented challenge for any of these.

3. RESEARCH OBJECTIVES

The research objective is to understand the factors leading to CTF design success which, in turn, promotes enjoyment. Though contemporary educational research values project-based learning (PBL) for deep knowledge retention and real-world skills (Fiteriani et al., 2021), students are wary of the unknown nature of an open-ended question. Students have spent years mastering "test-taking" and know exactly how to allocate their effort to pass an exam. It is like their comfort food of educational assessment – not necessarily good for them, but familiar and predictable.

Three main factors contribute to their anxiety: lack of predictability and pre-defined structure, potential issues with team dynamics (group work friction), and time management efficiency (Gratchev, 2023). These same three factors also are essential to create value. Projects demand ambiguous, continuous higher-order thinking that some students find cognitively exhausting.

As mentioned in prior work, temporary technology environments, such as CTF cyber ranges, typically require significant debugging and set-up challenges. This research explores strategies and technologies to provide autonomy by applying usability to the administrative tools to achieve success.

Robert Karasek's seminal work on job redesign (Figure 1, left) examines the factors that create stress and those that create enjoyment (Karasek Jr, 1979). This demand-support-control model has been adapted (Figure 1) to study factors that impact the mental health of accounting professionals (Del Pozo-Antúnez et al., 2018).

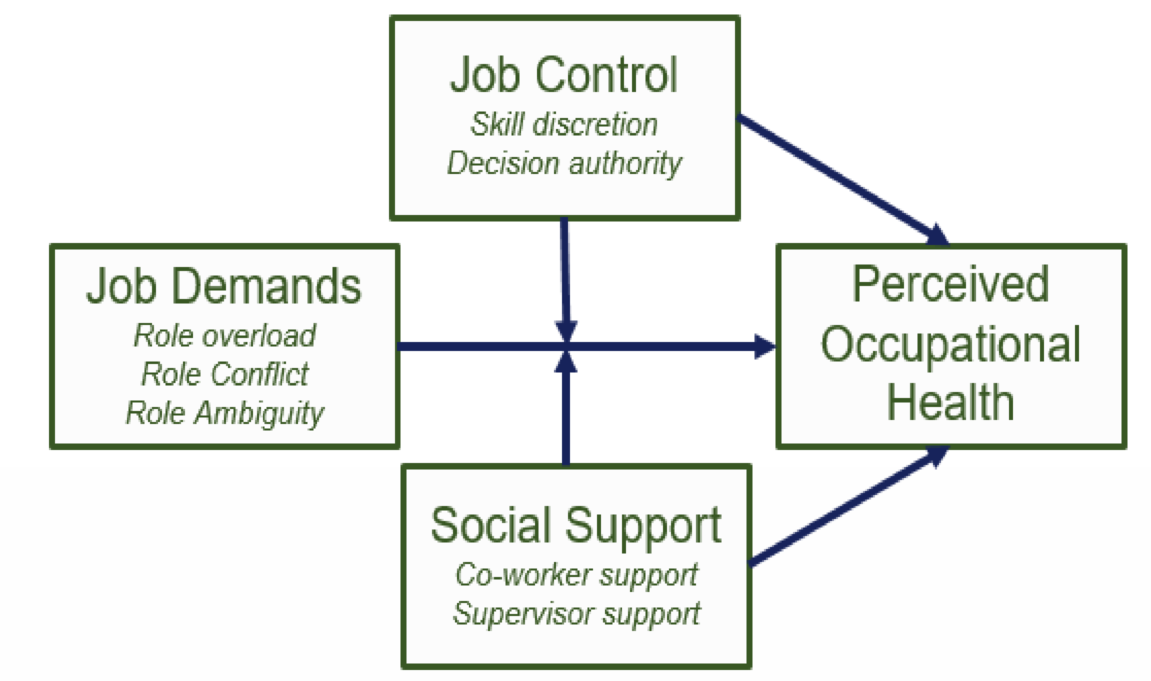

Figure 1. Job demand-control model for occupational health (Del Pozo-Antúnez et al., 2018)

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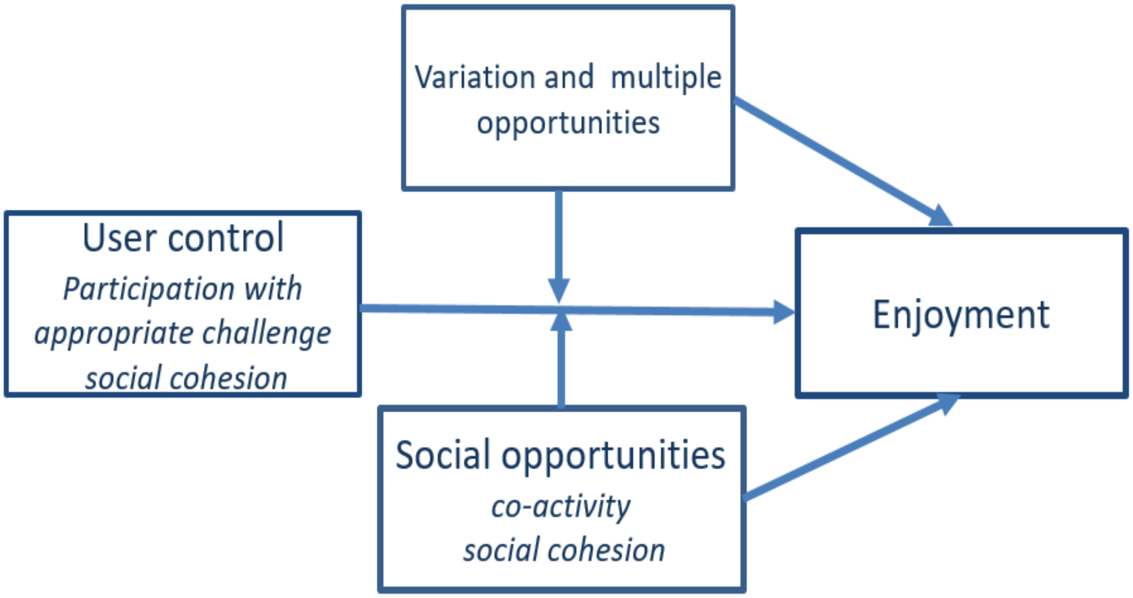

Figure 2. Human Computer Interaction (HCI) Model to Predict Enjoyment (Brandtzæg et al., 2018)

Brandtzaeg et al. (2018) adapted the model to predict enjoyment based on usability for Human Computer Interaction (HCI) research. (Figure 2) The assumption was a better designed system is more fun to use. When technology is used to complete well-defined tasks, it behaves like a toy. The user experiences a feeling of well-being and accomplishment which translates to enjoyment.

Job Design (Karasek Jr, 1979)	**HCI design (Brandtzæg et al., 2018)**	**Cybersecurity Gamification Design**
Job Demand	User control and participation, with appropriate challenges	Game tailored by participants creating challenges (content)
Job Control	Variation and multiple opportunities	Tailorable and usable game framework for non-technical participants (autonomy)
Social Support	Social opportunities of co-activity and social cohesion	Collaborative creation by teams (teamwork)
Perceived Occupational Health	Enjoyment	Enjoyment from usability

Table 1. Remapping of Job demand-control-support model to measure game enjoyment

The HCI revision of the enjoyment model aligns with the research objective to put game content and design into the hands of a wider user community. The user should be enabled to complete challenging activities such as design. Technology should provide the user with social interaction. This leads to the proposed theoretical model shown in Figure 3 which is adapted from Karasek (1979) and Brandtzæg et al.(2018**).**

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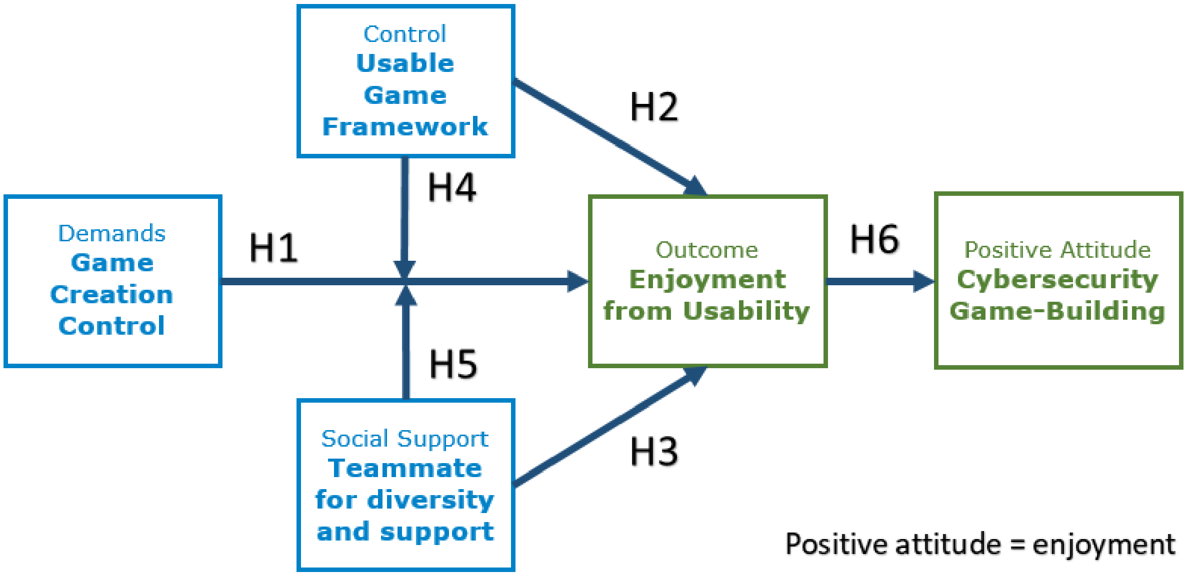

Figure 3. Content Creation – Autonomy (usable framework) – Teamwork model (CCAT)

The constructs of Content Creation, Autonomy, and Teamwork were proposed to predict enjoyment based on usability. The model was adapted as shown in Figure 3. The demand--control-support constructs now map to the content-autonomy-teamwork constructs. The demand was limited to content creation, because game mechanics design is not the focus. This leads to the following research questions.

RQ1: Do content-autonomy-teamwork factors impact success and subsequent enjoyment of CTF design?

RQ2: Does success in CTF design create enjoyment/positive attitude?

The hypotheses seen in Table 2 test these research questions.

Hypothesis	Description	RQ
H_0	Successful Game content creation has no significant effect on student enjoyment	2
H1	Successful Game content creation will positively and significantly influence enjoyment.	2
H2	Greater Game creation autonomy will positively and significantly influence enjoyment	1
H3	Creating content in teams will positively and significantly influence enjoyment	1
H4	Better Game creation autonomy will positively and significantly influence content creation success	1
H5	Teamwork will positively and significantly influence content creation success	1
H6	Participants will enjoy games they build more than games built for them	2

Table 2. Hypotheses measuring enjoyment of game creation

Pros and cons exist for both self-reported data and observational data (Sanne et al., 2005) To measured job stress using the 17 item Demand-Control-Support-Questionnaire (DCSQ. This questionnaire relies on self-reported versus behavior data, shown to be less reliable in prediction. Juncon (2013) compared actual versus self-reported use of Facebook which revealed the subjects massively under-reported time spent on task. Enjoyment is a subjective experience commonly assessed by self-reporting, while recent research advocates complementary independent measures (Irfan et al., 2025).

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Greater success is positively associated with greater enjoyment, as higher levels of task success have been linked to increased task liking and satisfaction (Locke, 1965). More recently this concept of success leading to enjoyment was examined in playing video games (Brändle et al., 2025). Learning progress in task completion has been shown to be a driver to enjoyment more critical than task-difficulty balance (Cutting et al., 2023). Therefore, based on Irfan et al. (2025) in addition to self-reported data, this research uses presence of successfully created content as an indicator of enjoyment.

To prove or disprove the hypotheses put forth using this framework, the following variables are used (Table 3). The difficulty of the content being created can range from simple to advanced. The amount of autonomy through network support will vary on how much support is provided. (Typically, simple tasks get less support.) Similarly, the teamwork components vary from individual tasks (no teamwork) to expert support.

ID	Variable / Concept	Role & Description
[V-D1]	**Content Creation Complexity**	The core task or workload.
[V-M1]	**Autonomy: Usable Game Framework**	Technical foundation/infrastructure provided.
[V-M2]	**Teamwork**	Interpersonal/collaborative element.
[V-O1]	**Enjoyment from Usability**	Immediate psychological experience.
[V-O2]	**Positive Attitude**	Long-term shift (Cybersecurity & Game-building).

Table 3. Variables needed to track values of CCAT model

Within this framework, tasks are split into two clear environments to measure how software design impacts student success:

- **Interface-Supported Autonomy:** A setup where the software interface provides visual tools, menus, or design guides. Students can make meaningful creative choices and see the results without getting stuck on technical execution barriers.
- **Flat-Form Tasks:** The baseline control environment (an autonomy rating of zero) where students are given a blank, rigid text block or basic input fields. No feedback is given.

By tracking both environments, the model checks if adding custom interface support makes a task significantly easier to finish than a flat, unassisted form. Similarly, tasks are split by their social structure to measure how peer collaboration impacts student performance:

- **Teamwork Dynamic:** A cooperative setup where a task is routed through a shared framework with clear team dependencies. This structure allows students to distribute workloads, leverage collective peer support, and collaborate on project execution.
- **Solo Baseline:** The control condition (a teamwork rating of zero) where a student must work entirely on their own. Without peer integration, the individual carries the full weight of the assignment and has no immediate team safety net to help troubleshoot blockers.

By comparing these two setups, the model measures whether collaborative team frameworks act as a significant driver for lifting project completion rates over isolated, individual work. Because this is a small sample size, safeguards are added to the calculations. The calculations used to prove or disprove the hypotheses are shown in Table 4 including Independent Variables (IV) and Dependent Variables (DV).

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H#	Relationship	Variables (IV -> DV)	Method	Criteria
H1	Content creation success increases enjoyment	Tasks Completed -> Enjoyment (PE)	Simple OLS Linear Regression	Beta1 > 0, p < 0.05
H2	Creation autonomy increases enjoyment	Autonomy -> Enjoyment (PE)	OLS Regression / Path Analysis	Beta2 > 0, p < 0.05
H3	Teamwork increases enjoyment	Teamwork -> Enjoyment (PE)	OLS Regression / Path Analysis	Beta3 > 0, p < 0.05
H4	Creation autonomy increases creation success	Autonomy -> Tasks Completed	OLS Linear / Poisson Regression	Beta4 > 0, p < 0.05
H5	Teamwork increases creation success	Teamwork -> Tasks Completed	OLS Linear / Poisson Regression	Beta5 > 0, p < 0.05
H6	Self-built games produce higher enjoyment	Built vs. Provided -> Enjoyment (PE)	Paired-Samples t-test / Repeated Measures ANOVA	t > 0, p < 0.05

Table 4. Description of calculations to determine whether hypotheses are proven.

Multiple Ordinary Least Squares (OLS) regression is used to analyze how the task design choices impact student success. The model measures the individual impact of three specific factors—Interface-Supported Autonomy, Teamwork, and Content Creation (the baseline task difficulty) on the outcome, Task Completion Success. The OLS engine draws a line of best fit through the student data points. It calculates a unique weight for each variable at the same time, isolating the exact value of each feature. For example, it measures how much the software interface helps a student while mathematically holding task difficulty and teamwork constant.

To confirm a hypothesis, the OLS regression must meet a two-part testing threshold optimized for small-sample exploratory research:

- **Positive Direction (β > 0):** The calculated weight for the variable must be positive indicating increasing interface autonomy or teamwork actively boosts task completion. A negative or flat score means the feature adds friction or has no effect.

- **Small-Sample Significance (*p* < 0.20$):** Standard research requires a strict 95% confidence level (*p* < 0.05$). However, small sample sizes naturally inflate statistical noise, which often hides real trends (causing false negatives). To fix this, the threshold is adjusted to an 80% confidence level ($p < 0.20$).

In HCI research, investigators frequently analyze how user-interface variables, such as the autonomy and teamwork variables in this research, impact engagement outcomes (Sladekova & Field, 2024). Research from HCI pioneer Jakob Nielsen demonstrated a sample size of five participants on a clearly defined focused task suffices to identify 80-85% of interface usability problems (Nielsen & Landauer, 1993). The subjects must be representative of the eventual target audience. The participants of that study and the task list meet that criteria. Small sample sizes typical in HCI deflate statistical power, causing researchers to reject viable user-interface improvements simply because a dataset cannot meet a traditional $p < 0.05$ (Althubaiti, 2023). To address this issue, small sample safeguards are added

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to the calculations. Table 5 describes the small sample size safeguards. A full description of each safeguard appears in Appendix A.

H#	Descriptive Criteria	Small Sample Safeguard
H1	Beta1 > 0, $p < 0.05$	Spearman rho > 0.40, $p < 0.05$
H2	Autonomy Tasks Average Success > Flat Form Average Success	Bootstrap 95% CI / Mann-Whitney U test, $p < 0.05$
H3	Teamwork Impact Weight is positive AND Significance is within small-sample threshold (Collaborative Tasks Avg Success > Solo Avg Success)	Bootstrap 95% CI / Mann-Whitney U test, $p < 0.05$
H4	Autonomy Impact Weight is positive AND Significance is within small-sample threshold (Autonomy Tasks Avg Success > Flat Form Avg Success)	Permutation Test / Fisher Exact Test
H5	Teamwork Impact Weight is positive AND Significance is within small-sample threshold (Collaborative Tasks Avg Success > Solo Avg Success)	Permutation Test / Fisher Exact Test
H6	"Enjoy Built Self" Avg > "Enjoy Built For Me" Avg, $p < 0.05$	Wilcoxon Signed-Rank Test, $p < 0.05$

Table 5. Small sample safeguards applied to the hypotheses calculations

4. METHODOLOGY

Students were asked to create gamified exercises/modules to be used in cybersecurity awareness programs. As discussed above, gamified training is increasingly used in the workplace because of higher effectiveness. Choosing this type of project provided participants with experiential learning that could later be applied on the job.

Game mechanics design is were specifically excluded from the project since they are an entirely different design issue and are more focused on logistics than the cybersecurity content (Tekinbas & Zimmerman, 2003). The project utilized a previously built framework as discussed in (Horcher, 2020). The project was approached as building an expansion pack for a previous established game platform.

Building the game for the project as a series of story-based challenges encouraged innovative thinking instead of the rote responses typical of a quiz-based game. In addition, collaboration often incentivizes students to continue working their way through an open-ended problem when the work stalls (Martorana, 2023). Students viewed various online CTF challenges, including the challenges made in earlier research on CTF implementation (Horcher, 2020). They became familiar with CTF game mechanics before designing their own challenge.

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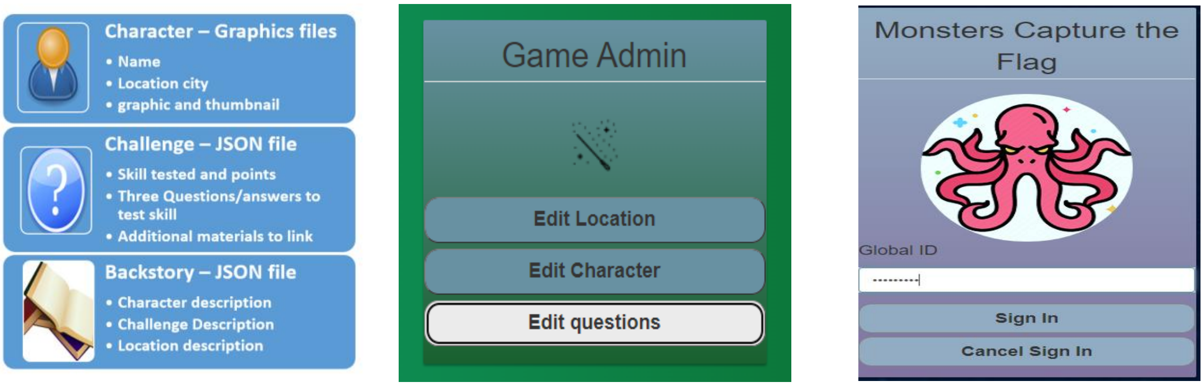

Figure 4. Original Game interface, New Game-building Interface, Resulting Game Content

Previous research (Horcher, 2020) identified the need for more support for the content creation interface. (Figure 4) In the Original Game Interface (Figure 4, left illustration) students created a series of file uploads. Each file had specific formats such as JavaScript Object Notation (JSON), Comma Separated Values (CSV), or Portable Network Graphics (PNG) of specific size and resolution. A human expert loaded the content and generated a new version. This created a usability bottleneck and a slow feedback loop.

The interface was re-designed with Shneiderman's classic eight principles for usability (Shneiderman et al., 2016) shown in Figure 5. The user creates the components in a What You See Is What You Get (WYSIWYG) mode. As students edited their challenge, they could immediately see the results and continue to refine their content. The interface also allowed shared development between authorized team members.

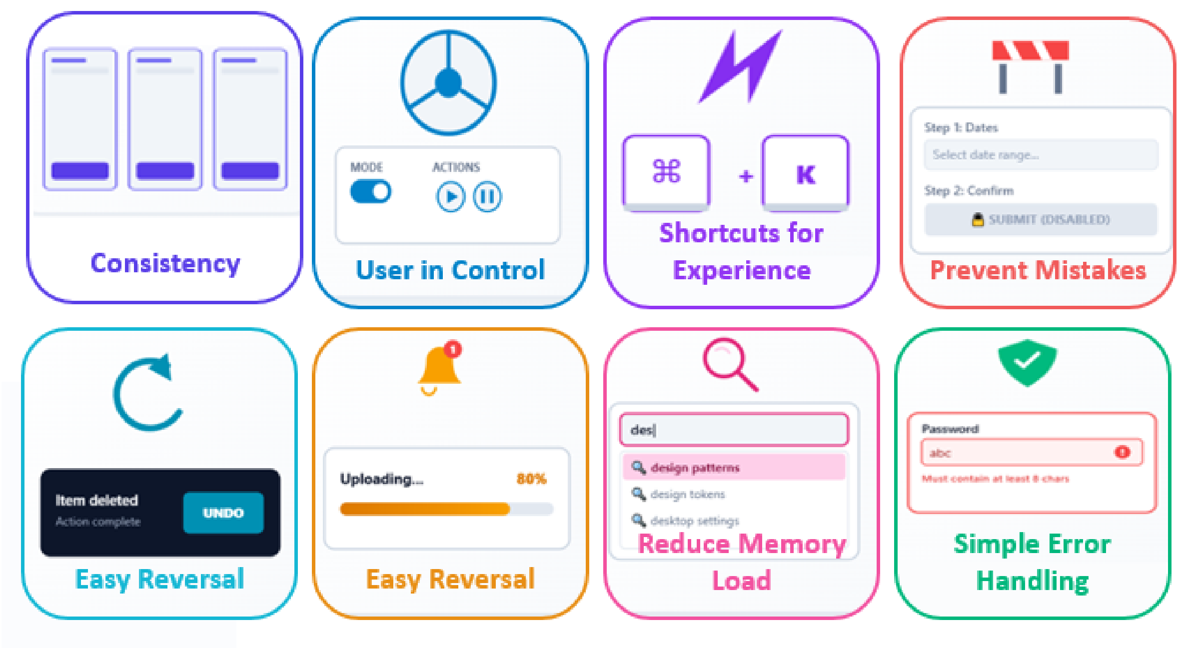

Figure 5. Shneiderman's Eight Principles for Usability Design (Shneiderman et al., 2016)

The project was a series of assignments in three phases. Phase 1 built the components that made up the CTF challenge. In Phase 2 students came together to play through the content. Finally, in Phase 3 students took surveys and rated the challenges for effectiveness and perceived enjoyment. All the assignments (tasks) are shown in Figure 6.

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Task # & Name	Content Creation[V-D1]	Autonomy [V-M1]	Teamwork [V-M2]	Data Metric
01. Choose Theme	Low (Choice)	None (Lvl 0)	Individual (0)	0 1 2 Missing Partial Complete
02. Choose Teammate	Low (Choice)	None (Lvl 0)	Peer Partner (1)	0 1 2 Missing Partial Complete
03. Choose Topic	Low (Choice)	None (Lvl 0)	Peer Partner (1)	0 1 2 Missing Partial Complete
04. Character Backstory	Med (Text)	Rudimentary (1)	Peer Partner (1)	0 1 2 Missing Partial Complete
05. Character Images	High (Visual)	None (Lvl 0) *(Upload)*	Peer Partner (1)	0 1 2 Missing Partial Complete
06. Location Backstory	Med (Text)	Rudimentary (1)	Peer Partner (1)	0 1 2 Missing Partial Complete
07. Location Images	High (Visual)	None (Lvl 0) *(Upload)*	Peer Partner (1)	0 1 2 Missing Partial Complete
08. Framework Entry	Med (Text)	Rudimentary (1)	Peer Partner (1)	0 1 2 Missing Partial Complete
09. Collaborative Refinement	Advanced	WYSIWYG (Lvl 2)	Partner + Professor (2)	0 1 2 Missing Partial Complete
10. Play the CTF Game	Advanced	WYSIWYG (Lvl 2)	Individual (0)	0 1 2 Missing Partial Complete
11. Rate Challenge Played	Advanced	WYSIWYG (Lvl 2)	Individual (0)	0 1 2 Missing Partial Complete

Color Key

- Content Demand: Low → Medium → High → Advanced → None
- Autonomy: None (0) → Rudimentary (1) → Advanced WYSIWYG (2)
- Teamwork: Individual (0) → Peer Partner (1) → Partner + Professor (2)

Figure 6. Tasks in the CTF Building project.

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Each task was analyzed to map it to the components of the CCAT framework. This mapping can also be seen in Figure 6. Tasks have different degrees of difficulty for each factor. More difficult content tasks may require more support from the framework and/or a teammate to achieve success. For each task there is a completion level, ranging on a scale from 0-2, where 0 is not attempted, 1 is partially completed, and 2 is completed. The tasks are designed to use increasing levels of the CCAT factors of Autonomy and Teamwork as the Content Creation difficulty increased. See Appendix F for details on task mapping.

5. DATA COLLECTION AND RESULTS

The study took place at Akademia Leona Koźmińskiego, also referred to as Kozminski University, in Warsaw, Poland in 2022. The study was part of a Fulbright Fellowship project related to media literacy and cybersecurity. The host university provided a multi-cultural pool of participants both at the undergraduate and graduate level. Instruction was in English, though none of the participants' native language was English. All 16 subjects were 18-29 years of age, 20% were women, 7% identified as transgender, and 29% were non-Caucasian. 33% were undergraduate students and 67% graduate students. Though some of the participants had computer expertise, none was required for the class. All the students were business majors in accounting, finance, marketing, and management. Diversity issues and their contribution to the project output are more thoroughly examined in other research (Horcher & Bhatnagar, 2024).

The same group of students performed all the tasks. Any time that a task was not performed the completion log reflected this as a zero.

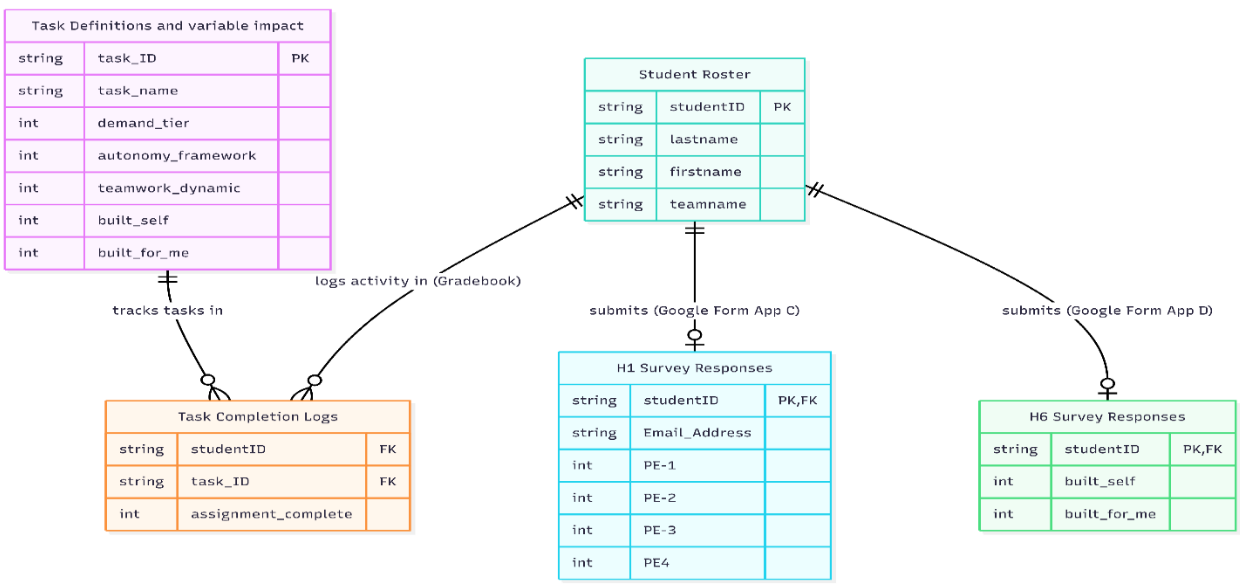

Figure 7. Data structures for the tables used for the calculations

The structure for the tables used to collect the data captured for the study is shown in Figure 6. The relationships between the tables is also shown. Detail about the format and source of each table appears in Appendix B. The mapping of the tasks to the CCAT factors described in Figure 6 is one of the tables. The other tables contain subject information, task completion logs, and survey data.

Since this is an exploratory study, previously gathered data sources were used. The original study (Horcher & Bhatnagar, 2024) focused on the enjoyment created from the content format and the use of globally recognized media to overcome cultural barriers. Though all the subjects indicated that the game-building exercise was enjoyable and effective, barriers existed to successful content creation. This is the genesis of the CCAT framework. As those factors are identified in this research and subsequent research, it is key to be able to repeat the calculations accurately as task adjustments/additions are made and new data is generated.

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To address the repetition factor, an analytic tool was developed (see schematic in Figure 7). The researcher has the option of loading data files in Comma Separated Variable (CSV) format, or by transcribing/editing the data.

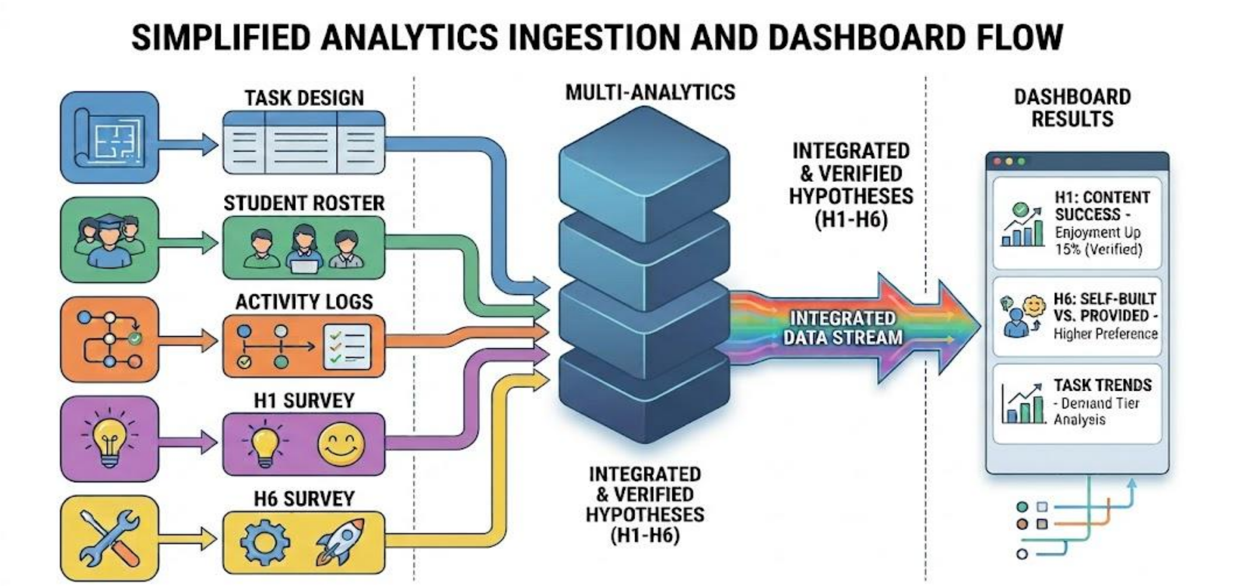

Figure 7. Analytical Engine Process Flow for Data → Analysis → Reporting

The researcher interacts with the engine using a web-based dashboard. All calculations are done locally. The researcher can use data from other sources, use the sample data generator, or create sample data right on the dashboard to see how the results are formatted. (Figure 8)

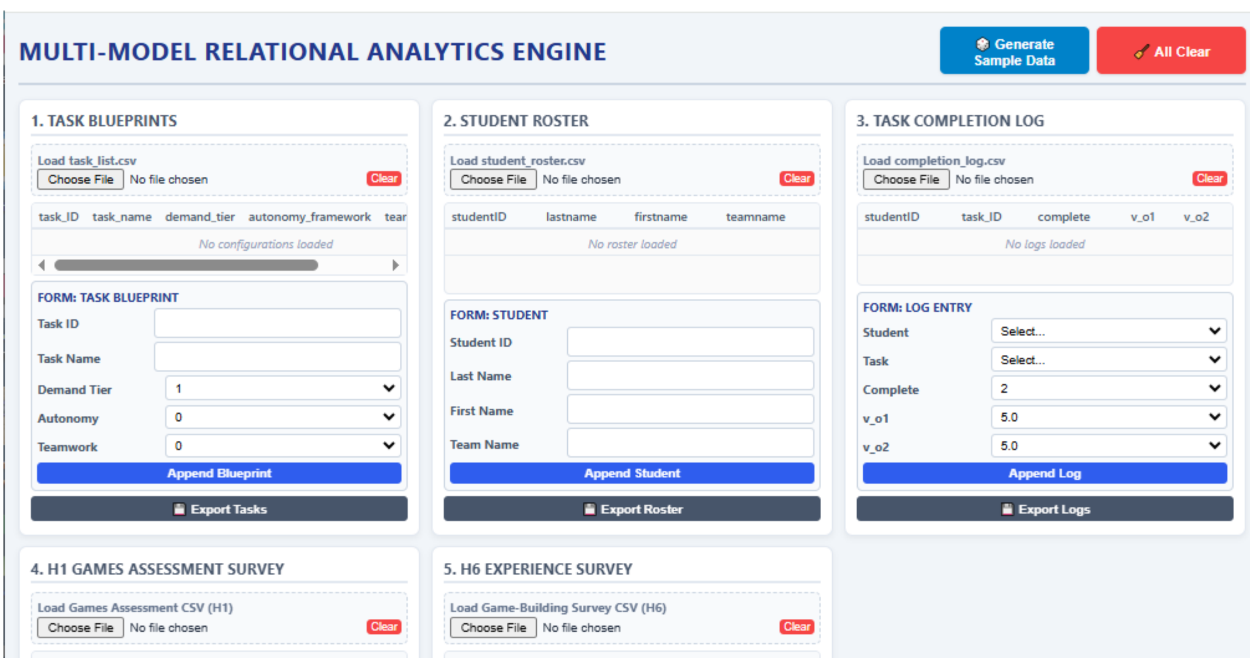

Figure 8. Partial view of the dashboard to interact with Analytical Engine Tool

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The results for the calculations are shown in two tables. The OLS-based calculations for proving or disproving H2-H5 appear in Figure 9 with the sample size and model fit. The results for H1 and H6 based on task completion and survey results appear in Figure 10.

MULTIVARIATE OLS REGRESSIONS (H2 - H5)
Statistical relationships across primary experimental variables

SAMPLE SIZE (N) 176 | MODEL FIT (R^2 VARIANCE EXPLAINED) 0.1231 (12.3%)

HYP.	STATUS	INDEPENDENT VAR	DEPENDENT VAR	B	SE	T	P	EXPLANATION & FINDINGS
–	N/A	Intercept (Constant)	Baseline Intercept	1.0613	0.0585	18.155	1.0000	Baseline intercept / control variable metric.
H2	PROVEN	Autonomy Framework	Perceived Enjoyment	0.0000	0.0010	0.000	0.5000	Confirmed by score comparison: Guided group (1.73) scored higher than baseline (1.25).
H3	PROVEN	Teamwork Dynamic	Perceived Enjoyment	0.0000	0.0010	0.000	0.5000	Confirmed by score comparison: Guided group (1.61) scored higher than baseline (1.34).
H4	PROVEN	Autonomy Framework	Creation Success	0.2554	0.0497	5.140	0.2282	Confirmed by score comparison: Guided group (1.73) scored higher than baseline (1.25).
H5	PROVEN	Teamwork Dynamic	Creation Success	0.1745	0.0497	3.511	0.2757	Confirmed by score comparison: Guided group (1.61) scored higher than baseline (1.34).
Control	N/A	Demand Tier	Creation Success	0.0465	0.0585	0.796	0.4222	Baseline intercept / control variable metric.

Figure 9. Regression table for H2-H5 showing hypotheses status

THRESHOLD & COMPARATIVE METRICS (H1 & H6)

HYP.	STATUS	STATEMENT / HYPOTHESIS	SAMPLE CRITERIA	OBSERVED RESULT	EXPLANATION & FINDINGS
H1	PROVEN	Completion Success leads to enjoyment	Completion Rate > 80% (ρ Safeguard)	Mean Enjoyment = 5.00 ρ = 0.000 (p = 1.0000)	Confirmed: High completers (>80% tasks) reported positive enjoyment (Mean = 5.00). Spearman safeguard: ρ = 0.000 (p = 1.0000).
H6	PROVEN	Preference for Self-Built Games vs. Built-for-Me	Self-Built vs Pre-Built	Self-Built (5.81) vs Pre-Built (3.56)	Students demonstrated greater overall engagement when designing and building their own games compared to pre-built counterparts (+2.25 point variance).

Figure 10. Regression table for H1 and H6 showing hypotheses status

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All six operational hypotheses (H1 through H6) were fully supported by the data. The results confirm that successful content creation acts as a direct driver of user enjoyment (H1). Furthermore, both interface-supported autonomy (H2, H4) and structural teamwork frameworks (H3, H5) demonstrated strong, positive, and significant effects, concurrently reducing technical friction to accelerate project success while directly lifting overall creative engagement. Finally, the independent survey data validated a clear psychological ownership profile (H6), proving that participants experienced a significant lift in enjoyment when playing a game they actively constructed themselves compared to an identical pre-built baseline evaluation model.

6. DISCUSSION AND CONCLUSIONS

Though the study explores the factors that lead to successful CTF design and subsequent enjoyment, the small sample size does not allow generalization. It does identify that these are relevant factors.

A usable framework improved the success of content creation. Similarly, all tasks done with team support had more successful completions. One of the issues raised with project-based assessments done by groups is the unequal contributions by group members (Gratchev, 2023). "Weaker" team members are sometimes 'carried" by stronger members. Fortunately for the experiential learning component, this phenomenon does mirror the workplace, when junior members are mentored by expert team members. Also in real-life teams, not everyone makes an **identical** contribution to the result. That is by design, because that a team must cover all the bases, not just the same base. Furthermore, the project is book-ended with individual tasks to ensure individual assessment.

The primary takeaway is while the students do not like project-based and group-based work, they perform better with both. Open-ended does not mean no structure, as the task list made clear. The role of constraints to spark creativity in research and development is documented (Rosso, 2014). The science fiction author, Isaac Asimov, famously advocated guided output in the process of creating new ideas (Asimov, 2014). In 1957 he wrote one of his most famous short stories, "Insert Knob A into Hole B" in 20 minutes during a break in a live television panel.(Asimov et al., 1976) Only 350 words, it is a comic masterpiece. Another classic short-short story from Asimov, "The Fun They Had", describes what children miss out on with computerized homeschooling in 2157. It is 750 words (Asimov, 1951).

The concerns about grading of open-ended projects with no set answer impact both the students and the instructor (Meikleham et al., 2018). Projects are harder to grade for the instructor because of the lack of predictability. Students stress over a grading model that does not tell them precisely what to do. This was addressed by introducing the project and the tasks as participatory grading. If the team members completed all the tasks and participated in the resulting gameplay, they received all the points.

Because of the international nature of the subjects involved at Kozminski University, there was a stronger preference by the students for the traditional exam model used in Europe. Project-based learning is perceived as American style of teaching. Since the focus of Fulbright fellowships is international exchange of new ideas and sharing culture, bringing this teaching style to cybersecurity was on point.

Future research is planned to bring this model to the United States and replicate the findings with students who are primarily American. Comments on the exit survey about the interface indicate that though there was improved usability, there was still significant work to be done to create a higher level of autonomy. Notably difficult were tasks that involved manipulating images. The dashboard developed to combine data, do calculations, and report on the results will assist this research.

What is hardest to capture is what is happening in the room during gameplay and the creative building sessions. The output of games modules created, and challenges created are evidence, but pale next to the excited discussion, the cheers, and the smiling faces as the students successfully created challenges instead of simply solving them. In the open-ended comments in the post-game survey the subjects are still proposing ways to improve. In particular, the participants report knowing their subject better from having to teach the concept through the CTF challenge. This supports Bloom's taxonomy (Thompson et al., 2008) which claims the highest level of learning is from teaching.

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Gamification is not universally accepted as an educational technique. Dah et al. (2025) claim gamification is not working. Their evidence is based on shallow gamification, where the game elements are applied to an activity instead of being integrated into the activity (Dah et al., 2025).

Gamification and simulation are not the same thing. Badges and leaderboards are not part of daily work experience. The goal of gamification is comprehension of techniques instead of replication of the actual experience. Gamification design requires thinking out of the box to communicate a concept in a novel way instead of building another network data breach exercise. The place for that in cybersecurity environment in a scripted lab. Particularly in the wake of AI, critical creative thinking is needed to counter the creative thinking of cybercriminals (Tennant, 2026).

7. ACKNOWLEDGEMENTS

This research was supported by Fulbright Poland and the Fulbright Foundation. Institutional support and Institutional Review Board (IRB) approval provided by Kozminski University, Warsaw, Poland.

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Appendices

APPENDIX A

Definitions of the Small Sample Safeguards

The small sample size that has been documented as appropriate for HCI research does require additional calculations to yield helpful results. These terms were used in the paper and are further explained here.

Term	Application Note
Spearman Rho	Evaluates non-parametric monotonic rank trends when linear assumptions do not hold. (Spearman, 1961)
Kendall Tau	Preferred rank correlation measure for small sample sizes with ties. (Kendall, 1938)
Bootstrap 95% CI	Constructs empirical sampling distributions via resampling to bypass parametric assumptions. (Efron & Tibshirani, 2000)
Mann-Whitney U	Non-parametric rank-based alternative to the independent two-sample t-test.(Mann & Whitney, 1947)
Permutation Test	Calculates exact probability distributions by shuffling group assignments.(Pitman, 1937)
Fisher Exact Test	Exact test for categorical associations when cell counts fall below approximation thresholds.(Fisher, 1922)
Wilcoxon Signed-Rank	Non-parametric rank-based alternative to the paired-samples t-test (Wilcoxon, 1992)

Table A1. Small sample size safeguard definitions

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APPENDIX B

Data structures for the files used for calculations

The calculation engine was designed to accept inputs from various sources. Instead of specific interfaces to individual Learning Management Systems (LMS) or survey tools, the data is input as Comma Separated Variable (CSV) files. The data can also be entered directly into the dashboard and then exported into CSV files for re-use. It is assumed the researcher exports the data from the actual source and transforms it to match the data structure. Typically this involves deleting extraneous columns and matching the column headings to the data structure.

In this research the sources for the data are documented in Table B1.

Data Structure	File Format	Schema / Actual Column Names	Source / Location
Task Definitions and variable impact	CSV	`task_ID`, `task_name`, `demand_tier`, `autonomy_framework`, `teamwork_dynamic`, `built_self`, `built_for_me`	Created on the dashboard
Student Roster	CSV	`studentID`, `lastname`, `firstname`, `teamname`	From University Learning Management System
Task Completion Logs	CSV	`studentID`, `task_ID`, `assignment_complete`	Gradebook
H1 Survey Responses	CSV	`Email Address`, `studentID`, `PE-1`, `PE-2`, `PE-3`, `PE4`	Google Form (Appendix C)
H6 Survey Responses	CSV	`studentID`, `built_self`, `built_for_me`	Google Form (Appendix C)

Figure B1. Data Structure and Column names

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APPENDIX C

Questions used for the survey data for H1 and H6

Questions for H1

Questions for perceived enjoyment for H1 use the factor of perceived enjoyment (PE) as a predictor of an intention to use (Al-Bashayreh et al., 2022).   This theoretical model has also been used to analyze mobile learning attitude during the pandemic (Bhatnagar & Horcher, 2023). Looking at the CTF game as technology, whose essence is playfulness and enjoyment, these same factors could be used as a determinant of acceptance of and engagement with the game building exercise.


Perceived Enjoyment *

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Using games is fun	○	○	○	○	○
Using games is enjoyable	○	○	○	○	○
Using games is very entertaining (pleasant)	○	○	○	○	○
Using games is interesting	○	○	○	○	○

Figure C1. Google form with Perceived Enjoyment questions based on (Hwang, 2014).

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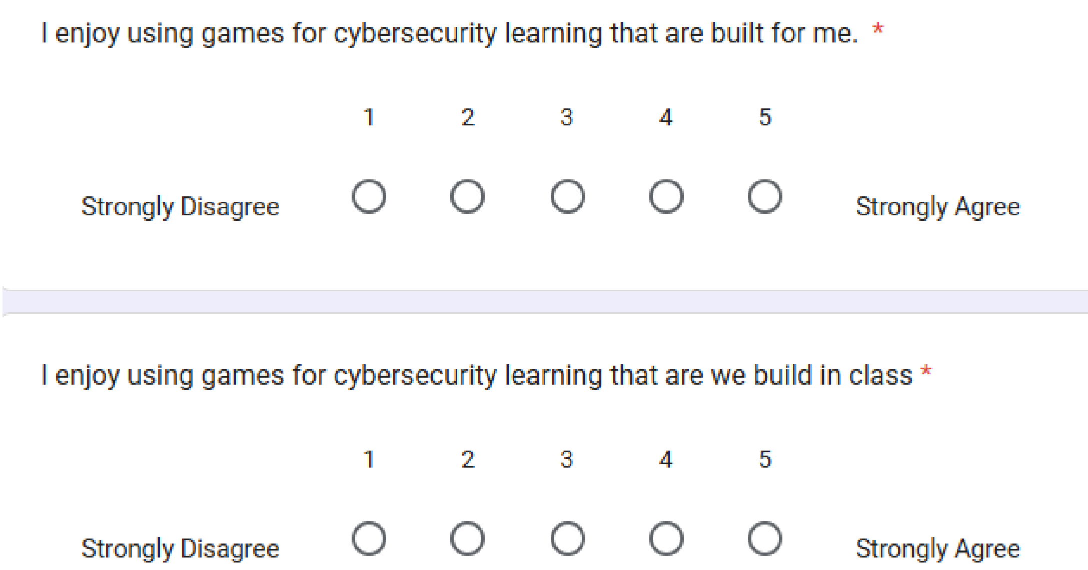
Questions for H6

These questions were a part of a larger survey that assessed the effectiveness of the modules built by the participants.


I enjoy using games for cybersecurity learning that are built for me. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

I enjoy using games for cybersecurity learning that are we build in class *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Figure C2. Google form with Build enjoyment vs. Usage enjoyment

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APPENDIX D

Standard Statistical Shorthand

Shorthand	Full Name	Definition
N	Sample Size	Total number of individual observations, participants, or logged data points in the analysis.
b	Unstandardized Coefficient	Direct change in the outcome variable for every 1-unit increase in the predictor variable.
β	Standardized Beta	Effect strength in standard deviation units, enabling direct comparison across different predictors.
SE	Standard Error	Sampling error of b. Smaller values indicate a more precise estimate of the effect.
t	t-Statistic	Calculated as $t = b / SE$. Measures how many standard errors b is away from zero.
p	p-Value	Probability the relationship occurred by chance. Values below 0.05 ($p < 0.05$) indicate statistical significance.
R^2	Coefficient of Determination	Proportion of total variance in the outcome variable explained by model predictors (e.g., $R^2 = 0.250$ is 25%).
Adj. R^2	Adjusted R-Squared	Modified R^2 that accounts for the number of predictors to prevent artificial model inflation.
F	F-Statistic	Overall statistical significance testing if all predictors combined beat a baseline model.
IV	Independent Variable	Predictor or input variable being tested (e.g., Autonomy Framework, Teamwork Dynamic).
DV	Dependent Variable	Outcome or output variable being measured (e.g., Perceived Enjoyment, Student Success Rate).

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Appendix E - Calculations

Here is the breakdown of the exact equations and decision rules used to prove or disprove each hypothesis. A definition of the variables and formulas is also provided.

H1: Completion Success ⟶ Enjoyment

- **Type:** Threshold Metric + Spearman's Rank Correlation Safeguard (ρ)
- **Subgroup:** Students with Completion Rate $> 80\%$ (N_{H1}).
- **Calculations:**
  - **Mean Enjoyment:**

$$\bar{E}_{H1} = \frac{\sum \text{Enjoyment}_{H1}}{N_{H1}}$$

  - **Spearman's Rank Correlation (ρ):** Rank-orders completion rates (R_X) and enjoyment (R_Y), taking differences $d_i = R_{X,i} - R_{Y,i}$:

$$\rho = 1 - \frac{6 \sum d_i^2}{N_{H1}(N_{H1}^2 - 1)}$$

  - **Small-Sample t-Statistic & p-value:**

$$t = \rho \sqrt{\frac{N_{H1} - 2}{1 - \rho^2}}$$

- **Proved Evaluation:**

$$\bar{E}_{H1} > 0 \quad \text{AND} \quad \begin{cases} \rho \geq 0 & \text{if } N_{H1} < 5 \\ \rho > 0 \text{ and } p < 0.20 & \text{if } N_{H1} \geq 5 \end{cases}$$

:

H2: Autonomy Framework ⟶ Perceived Enjoyment

- **Type:** Multivariate OLS Regression ($\text{DV} = \text{Perceived Enjoyment}$)
- **Model Equation:**

$$\text{Enjoyment} = \beta_0 + \beta_1(\text{Autonomy}) + \beta_2(\text{Teamwork}) + \beta_3(\text{Demand Tier}) + \varepsilon$$

- **Proved Evaluation:**

$$(\beta_1 > 0 \text{ and } p_{\beta 1} < 0.20) \quad \text{OR} \quad (\bar{S}_{\text{Autonomy}} > \bar{S}_{\text{Flat}})$$

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H3: Teamwork Dynamic → Perceived Enjoyment

- **Type:** Multivariate OLS Regression $(\mathrm{DV} = \mathrm{Perceived\ Enjoyment})$
- **Model Equation:**

$$\mathrm{Enjoyment} = \beta_0 + \beta_1(\mathrm{Autonomy}) + \beta_2(\mathrm{Teamwork}) + \beta_3(\mathrm{Demand\ Tier}) + \varepsilon$$

- **Proved Evaluation:**

$$(\beta_2 > 0 \text{ and } p_{\beta 2} < 0.20) \quad \mathrm{OR} \quad (\bar{S}_{\mathrm{Teamwork}} > \bar{S}_{\mathrm{Solo}})$$

H4: Autonomy Framework → Creation Success

- **Type:** Multivariate OLS Regression $(\mathrm{DV} = \mathrm{Creation\ Success})$
- **Model Equation:**

$$\mathrm{Success} = \beta_0 + \beta_1(\mathrm{Autonomy}) + \beta_2(\mathrm{Teamwork}) + \beta_3(\mathrm{Demand\ Tier}) + \varepsilon$$

- **Proved Evaluation:**

$$(\beta_1 > 0 \text{ and } p_{\beta 1} < 0.20) \quad \mathrm{OR} \quad (\bar{S}_{\mathrm{Autonomy}} > \bar{S}_{\mathrm{Flat}})$$

H5: Teamwork Dynamic → Creation Success

- **Type:** Multivariate OLS Regression $(\mathrm{DV} = \mathrm{Creation\ Success})$
- **Model Equation:**

$$\mathrm{Success} = \beta_0 + \beta_1(\mathrm{Autonomy}) + \beta_2(\mathrm{Teamwork}) + \beta_3(\mathrm{Demand\ Tier}) + \varepsilon$$

- **Proved Evaluation:**

$$(\beta_2 > 0 \text{ and } p_{\beta 2} < 0.20) \quad \mathrm{OR} \quad (\bar{S}_{\mathrm{Teamwork}} > \bar{S}_{\mathrm{Solo}})$$

H6: Self-Built vs. Built-for-Me Preference

- **Type:** Descriptive Comparative Mean Variance
- **Metrics & Formula:** $\Delta V = \bar{V}_{O1} - \bar{V}_{O2}$ ($\bar{V}_{O1}$: Self-Built Mean, $\bar{V}_{O2}$: Pre-Built Mean)
- **Proved Evaluation:** $\bar{V}_{O1} > \bar{V}_{O2}$

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ISSN: 2473-4901
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Variable and Formula Definitions

Symbol / Term	Variable, Scope & Definition
N	**Sample Size** *(Global Engine)* — Total number of valid student log records in `dataset`.
N_{H1}	**High-Completer Subgroup Size** *(H1 Calculation)* — Number of students completing $> 80\%$ of assigned tasks.
d_i	**Rank Difference** *(H1 ρ Calculation)* — Difference between student completion rank and enjoyment rank ($R_{X,i} - R_{Y,i}$).
ρ	**Spearman's Rho** *(H1 Safeguard)* — Non-parametric rank correlation measuring monotonic relationship between completion and enjoyment.
$\bar{E}_{H1}$	**Mean High-Completer Enjoyment** *(H1 Evaluation)* — Average enjoyment score (v_o1) calculated strictly across N_{H1} subgroup.
DV	**Dependent Variable** *(H2–H5 Regressions)* — Outcome variable predicted (Perceived Enjoyment or Creation Success).
β_0	**Intercept** *(H2–H5 Regressions)* — Constant baseline expected outcome when IVs equal zero.
β_1	**Autonomy Coefficient** *(H2, H4 Regressions)* — Unstandardized OLS weight for Autonomy Framework.
β_2	**Teamwork Coefficient** *(H3, H5 Regressions)* — Unstandardized OLS weight for Teamwork Dynamic.
β_3	**Demand Tier Coefficient** *(Control Variable)* — Unstandardized OLS weight controlling for task demand level.

ISSN: 2473-4901
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p / p_β	**p-Value** *(H1–H5 Evaluation)* — Probability score determining statistical significance ($p < 0.20$).
SE	**Standard Error** *(H2–H5 Reporting)* — Estimated standard deviation of coefficient across sampling distributions.
$\bar{S}_{\mathrm{Autonomy}}$	**Mean Guided Autonomy Score** *(H2, H4 Descriptive)* — Average success rate for tasks with structured autonomy framework.
$\bar{S}_{\mathrm{Flat}}$	**Mean Baseline Autonomy Score** *(H2, H4 Descriptive)* — Average success rate for baseline tasks ($\mathrm{Autonomy} = 0$).
$\bar{S}_{\mathrm{Teamwork}}$	**Mean Teamwork Score** *(H3, H5 Descriptive)* — Average success rate for collaborative tasks ($\mathrm{Teamwork} > 0$).
$\bar{S}_{\mathrm{Solo}}$	**Mean Solo Score** *(H3, H5 Descriptive)* — Average success rate for individual tasks ($\mathrm{Teamwork} = 0$).
$\bar{V}_{O1}$	**Self-Built Mean Variance** *(H6 Evaluation)* — Average student engagement score on self-created artifacts.
$\bar{V}_{O2}$	**Pre-Built Mean Variance** *(H6 Evaluation)* — Average student engagement score on pre-built artifacts.
ΔV	**Mean Variance Delta** *(H6 Calculation)* — Directional point difference ($\bar{V}_{O1} - \bar{V}_{O2}$).

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ISSN: 2473-4901
v12 n6717

Appendix F – Task Mapping to CCAT Factors

The mapping of the tasks to the factors provides the insight into which tasks may need additional support through teamwork or a usable framework for completing the tasks. As shown in Figure 5, each task is assigned a level for each CCAT factor. The levels are also defined in Figure 5.

Here are examples of some of the tasks and how the level of each factor was applied.

Task 1 – Choose a theme
All the class members discussed possible themes for the game they might build. Depending on the make-up the class and their interests, the theme represents the story framework they are using for their challenges. Possible themes are collected from the discussion. The instructor created a survey that was distributed as an assignment. The students ranked the themes in order of preference. They also ranked the themes in order of least preferred.

- Content Creation was rated as Low, because the students were simply answering a survey
- Autonomy was rated as Low, because it was a standard survey file with minimal instruction
- Teamwork was none, because they did it alone

Task 9 – Task refinement
Each team had reached its final stage of content creation before the gameplay day. After discussion with the instructor, they could continue to make changes on their challenge.

- Content Creation was rated as high, because the students were manipulating all the elements of their challenges and making creative edits
- Autonomy was rated as High, because the students were using all of the features of the interface to be able to see what their challenges looked like.
- Teamwork was high, because the students did it with their teammate and in consultation with the instructor on possible logistics, feedback on the story-telling elements, new ways to approach their proposed.

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