Design and Classroom Implementation of a Self-built Gamified Platform for Cyber-defense Education

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***Abstract*—Hands-on cyber-defense training often requires specialized platforms that are costly, difficult to customize, or restrictive of instructor control. This paper presents the design, classroom implementation, and exploratory evaluation of a self-built, low-cost gamified platform for National Collegiate Cyber Defense Competition (NCCDC)-oriented cybersecurity education. The platform integrates a two-phase instructional structure with points, public rankings, badges, and small tangible rewards to support experiential learning and student engagement. The evaluation included a pilot cohort (n = 8), a supplementary scenario-based survey (n = 34), platform activity logs, and instructor observations. Results indicate that students generally perceived the gamified design positively. Public rankings were viewed as the strongest motivational feature, while points were considered the most useful for tracking learning progress. Badges and gift card rewards also received favorable responses, although some students preferred private feedback. The proposed platform demonstrates a practical, instructor-controlled framework for delivering customizable, low-cost cyber-defense training while integrating gamification with staged instructional design. Because the study was conducted in a single course with a small sample, the findings should be interpreted as exploratory.**

***Keywords*—cybersecurity, cyber-defense, gamification, course design, hands-on training**

I. Introduction

Instructors in cybersecurity continue to face challenges, particularly in choosing suitable tools, developing effective instructional content and methods, and sustaining student retention and engagement. While cybersecurity education increasingly emphasizes hands-on experiential learning environments [1, 2], building and maintaining such environments in practice is often resource-intensive and pedagogically complex [3]. Existing solutions, including commercial and cloud platforms, can provide scalable training environments [4]. However, some platforms may limit instructor customization and control [5]. In addition, cloud-based or commercial systems can introduce recurring costs [6]. These limitations are particularly restrictive for cyber-defense course offerings that require flexible, evolving, and scenario-based training environments.

In addition, continued student engagement is another key issue in cybersecurity education. Many current platforms include gamification features designed to enhance student engagement [1]. Despite growing interest in experiential learning and gamification in cybersecurity education [7, 8], there remains a gap in understanding how low-cost, instructor-controlled platforms can be designed and whether such designs effectively support both technical skill development and sustained student engagement [3, 9].

Gamification is a recognized strategy for enhancing student engagement; however, current research often isolates platform features from the broader instructional design. Prior studies have explored gamified learning environments [7, 10, 11]. Yet those studies mostly focus on platform features or student perceptions without details about integrating platform design, instructional structure, and engagement mechanisms into a unified framework [3].

To address these gaps, this study investigates the design and classroom implementation of a self-built, low-cost cyber-defense training platform integrated with a structured, gamified course design. The authors developed the platform to support practical activities such as system hardening, service maintenance, and incident response to evolving cyber-attack scenarios, while maintaining full instructor control and adaptability. Although this design was implemented in the context of a preparation course for the National Collegiate Cyber Defense Competition (NCCDC) [1], it is also intended to be adopted in broader cyber-defense training settings.

This study is guided by the following Research Questions (RQ):

RQ1: How can a low-cost, instructor-controlled platform be designed to support experiential cyber-defense training?

RQ2: To what extent does the integration of gamification elements (e.g., points, rankings, badges, rewards) support student engagement and participation?

RQ3: How does a two-phase training structure (technical skill development and team-based simulation) contribute to students' perceived learning and skill development?

To investigate these questions, the course design was implemented in two phases: (1) individual technical skill development with measurable task objectives, and (2) team-based cyber-defense simulations emphasizing communication, coordination, and leadership. Gamification elements were embedded throughout both phases to support motivation and feedback. To evaluate the effectiveness of the course design, this study adopts an exploratory approach using multiple sources of evidence.

This paper contributes to cybersecurity education research in three ways. First, it proposes a design framework for developing low-cost, instructor-controlled cyber-defense training platforms that are fully customizable and cost-effective. Second, it demonstrates how gamification mechanisms can be integrated systematically with staged instructional design rather than applied as isolated features. Third, it provides empirical insights from classroom implementation, offering early evidence on how such design influences student engagement and perceived learning outcomes. While the study is based on a single course with a

limited sample size, the findings offer practical implications for designing scalable and adaptable cyber-defense training environments.

II. Literature Review

A. Cybersecurity Training Environments and Educational Platforms

Hands-on practice is central to cybersecurity education because cybersecurity skills are best developed through authentic learning experiences and practical problem solving [12]. Situated learning further suggests that learners develop expertise through participation in authentic communities of practice [13]. Recent cybersecurity education research also emphasizes the importance of preparing learners for evolving cyber threats through practice-oriented instruction [14]. Accordingly, cybersecurity education has increasingly adopted cyber ranges, competition platforms, and virtual laboratories to support experiential learning [1, 2]. Specialized systems such as CyExec demonstrate the feasibility of reusable cyberattack and defense exercises [4], while more recent work has extended these ideas through hybrid training environments and adaptive learning platforms [6, 9]. Collectively, these studies suggest that effective cybersecurity education depends not only on technical capabilities but also on how well the training platforms support instructional objectives.

Existing platforms provide scalable training environments [4]. However, some platforms limit instructor customization and control when adapting exercises to course-specific objectives [5]. Cloud-based or institutionally managed environments may also introduce recurring operational costs and infrastructure dependencies [6]. As a result, instructors must balance the convenience of existing platforms with the flexibility needed to support their own pedagogical goals [12]. Although prior work has extensively examined platform capabilities and cyber-range architectures [1, 2], relatively little attention has been given to designing low-cost, instructor-controlled environments that tightly integrate technical infrastructure with course-specific instruction.

B. Gamification in Cybersecurity Education

Gamification has been widely adopted to improve learner motivation, engagement, and persistence in educational settings [8, 11]. Recent work on digital gamification further emphasizes that game elements can support engagement, but only when they are meaningfully aligned with instructional goals [15]. Research has shown that game-based learning can enhance student participation and learning experiences in technical education [16]. Similar benefits have been reported in business analytics and supply chain education using gamified instructional approaches [17, 18]. However, the effectiveness of individual gamification elements is influenced by learner characteristics and instructional context rather than by the game elements themselves. For example, learners with different competitiveness traits respond differently to leaderboard rankings [19], while points and rankings do not consistently improve learning outcomes across all settings [20, 21].

Within cybersecurity education, research has shifted from studying isolated game mechanics toward integrating gamification into learning platforms and hands-on laboratory environments [5, 10]. Recent reviews of cybersecurity gamification similarly conclude that many studies focus on individual game features, awareness activities, or specific platforms rather than integrated instructional frameworks [22, 23]. This suggests that limited attention has been given to how multiple gamification mechanisms work together as a coherent instructional system within authentic cyber-defense training environments.

Hands-on cybersecurity training also typically progresses from individual skill development to collaborative, scenario-based activities. This progression is consistent with experiential learning, which emphasizes learning through concrete experience and reflection [12], and with situated learning, which emphasizes authentic participation in real-world practice [13]. Cybersecurity education research likewise recognizes the value of structured competitions and staged training environments for developing practical skills [2, 16]. Welu [24] emphasized that Collegiate Cyber Defense Competition (CCDC)-style competitions expose students to realistic operational environments through progressive team-based exercises. Anand *et al.* [25] similarly found that computing competitions strengthen both technical competencies and broader curricular outcomes. Nevertheless, few studies examine how staged instructional structures interact with platform design and integrated gamification strategies to support learning throughout an entire cybersecurity course.

C. Research Gap and Position of This Study

Overall, prior research highlights the value of hands-on platforms and gamification, but three key gaps remain.

First, existing research has developed a wide variety of cybersecurity platforms, cyber ranges, and online learning environments [1, 2]. Specialized systems have also demonstrated effective support for practical cyberattack and defense exercises [4, 6]. However, relatively little attention has been given to low-cost, instructor-controlled environments that tightly integrate technical infrastructure, learning activities, and feedback within a specific course.

Second, although gamification has been widely studied in both education and cybersecurity [8, 11], recent reviews conclude that most cybersecurity gamification research focuses on individual game elements, awareness interventions, or specific platform implementations [22, 23]. Broader gamification research also emphasizes that game elements should be integrated with instructional design rather than added as isolated motivational features [15]. Consequently, less is known about how multiple gamification mechanisms function together as a coherent instructional system throughout authentic cyber-defense training.

Third, experiential learning emphasizes learning through authentic experience [12], while situated learning stresses progressive participation in real-world practice [13]. Although cybersecurity education research recognizes the value of structured competitions and staged learning environments [24, 25], relatively few studies investigate how progression from individual exercises to team-based simulations interacts with platform design and gamification to support learning outcomes.

This study addresses these gaps by examining a self-built,

low-cost platform that integrates platform design, staged instructional structure, and multiple gamification elements within an NCCDC-oriented course. By focusing on how these components interact, the study provides insight into how technical infrastructure, instructional design, and engagement mechanisms can be jointly organized to support cybersecurity education.

III. System Design

This section describes the proposed course and platform design, implementation, and preliminary evaluation process. The platform demonstrated here is built for a student training course based on the National Collegiate Cyber Defense Competition (NCCDC) [1]. Fig. 1 illustrates the study process.

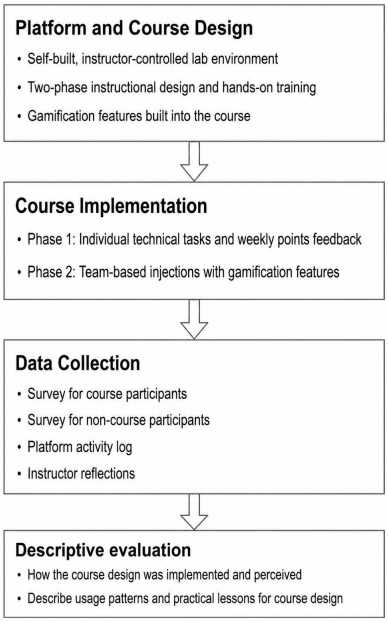


Fig. 1. Overall study process: platform design, course implementation, data collection, and evaluation.

A. Course Context and Instructional Design

NCCDC is a comprehensive cybersecurity competition [1]. Students need to develop two broad sets of skills. The first involves teamwork and administrative skills, including leadership, communication, incident response planning, and task coordination. The second set involves technical skills, including Windows and Linux hardening, network and firewall configurations, service configurations and reconfigurations (e.g., web systems, Active Directory service, Domain Name System (DNS), Simple Mail Transfer Protocol (SMTP), Post Office Protocol version 3 (POP3), and File Transfer Protocol (FTP)), and system backup and restoration.

Technical skills are fundamental and can be acquired individually. Thus, there is a natural sequence to train the technical skills first before the team and collaboration skills since students cannot properly collaborate on the team tasks without proficient technical skills.

The overall training was organized into two instructional phases between April and November 2024. Phase 1 ran from April 12 to June 7, 2024, and focused primarily on individual technical skills. In the weekly training sessions, students completed instructor-led system administration tasks individually. These tasks emphasized core technical capabilities such as installing, testing, debugging, and customizing applications and services.

Phase 2 ran from August 23 to November 1, 2024. It built on the technical skills developed in Phase 1 while placing greater focus on team collaboration, communication, and task coordination. During this phase, students worked on business injections that required both technical problem-solving skills and coordinated team responses, while simulating routine operational tasks such as user management, service customization, security patching, documentation and reporting, and security policy implementation. These tasks were designed to reinforce students' technical competence while also requiring them to coordinate their efforts in a more collaborative way.

B. Platform Design

The ideal platform in the NCCDC context would be a full replica of the actual competition virtual environment. However, because the environment is not publicly available as an open system, the authors used the 2024 Midwest CCDC team pack as a reference to replicate the setup. Fig. 2 below illustrates the network topology. It included a Palo Alto firewall, multiple Windows and Linux servers, and a series of crucial services hosted across those devices.

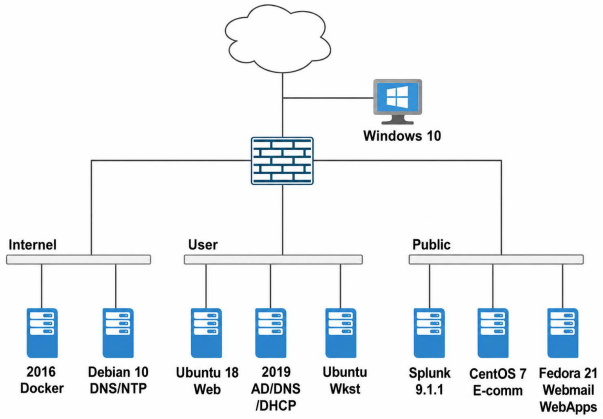


Fig. 2. 2024 Midwest CCDC network topology.

To replicate the environment, the authors used the following physical devices for the setup: a Palo Alto PA 440 firewall, four Cisco 350 series managed switches, and a Dell PowerEdge R720 server with 24 logical processors, 96 GB memory, 6 TB storage space, and 8 ethernet interface cards. All devices were obtained from university surplus or through donations.

Each Cisco switch is connected to a dedicated interface on the Palo Alto firewall, creating subnets corresponding to the "Internal", "User", "Public", and "External" zones outlined in the topology (Fig. 2). The Windows 2019 Datacenter edition was installed on the Dell PowerEdge R720 server as the hosting operating system to set up the Windows and Linux servers. Next, VirtualBox was installed as a Type 2 hypervisor and was used to create the necessary Windows and Linux virtual machines to represent the servers listed in the topology. Each virtual machine was assigned a network interface card connected to the corresponding switch's designated subnet. Then the IP address was configured, and the relevant services were installed as outlined in the

topology (Fig. 2) on each of the virtual machines. Table 1 below describes the hardware configuration, virtual machines, and service software versions used in building the platform.

Table 1. Platform configurations

Category	Component	Name	Description	Item Count
Hardware	Firewall	Palo Alto	Model: PA-440; Version: 10.1.9-h3	1
	Network Switches	Cisco	Model: CBS350-8T-E-2G Managed Switch, 8 Port GE	4
	Server[1]	Dell	Model: PowerEdge R720: CPU:2 Intel Xeon E5-2360 2.30 GHZ 6 Cores; 96 GB RAM; 6 TB Storage	
Software	Hosting OS	Windows server 2019	Edition: Windows 2019 Datacenter 10.0.17763	1
	Hypervisor	VirtualBox	Version: VirtualBox 7.0.14	1
	Virtual Machine (VM)[1]	Windows 10 Desktop	3 Processors; 8 GB RAM; 256 GB Storage	1
	VM	Windows Server 2016	3 Processors; 8 GB RAM; 256 GB Storage	1
	VM	Debian 10	1 Processor; 2 GB Memory; 60 GB Storage	1
	VM	Ubuntu 18 Server	1 Processor; 2 GB Memory; 30 GB Storage	1
	VM	Windows Server 2019	4 Processors; 8 GB RAM; 256 GB Storage	1
	VM	Ubuntu 18 Desktop	1 Processor; 2 GB Memory; 60 GB Storage	1
	VM	Centos 7—Splunk	1 Processor; 2 GB Memory; 60 GB Storage	1
	VM	Centos 7—eCommerce	1 Processor; 2 GB Memory; 60 GB Storage	1
	VM	Fedora 21—Webmail	1 Processor; 2 GB Memory; 60 GB Storage	1

[1] All virtual machines are hosted within the Dell R720 server.

C. Gamification Design

The mainstream gamification techniques in education include points, badges, leaderboards, and levels [19]. The first three techniques are applied in this course design as described below. The design did not incorporate levels because lower-level placement could create unnecessary stress for students.

The gamification design was layered onto the instructional process differently across the two phases. In Phase 1, the instructor evaluated each student's work after each training session and assigned points based on task completion quality. These points were communicated through weekly emails individually and were used primarily for self-assessment and progress tracking rather than for public comparison or competition. In Phase 2, the point system remained while the instructor introduced additional gamification features. Students worked in small teams on business injections, and the instructor evaluated the quality of each team's work and assigned points accordingly. In this phase, students were informed that several additional recognition mechanisms would be used: (1) the public display of the Top 4 performers based on points earned, (2) peer-elected badges, and (3) gift card rewards for the Top 4 performers by cumulative points.

The public Top 4 display was intended to visibly recognize students' achievements and encourage continued participation. In addition, two badges—Top Communication and Top Know-How—were awarded at the end of Phase 2 to recognize standout participants. The instructor designed these badges to reinforce the expectations regarding students' technical competence and team-related performance. The students elected the badge winners based on peer observations during Phase 2. The physical badges were embroidered onto T-shirts brought by the winners. With departmental support, gift card rewards totaling $200 were also awarded to the Top 4 performers by total points earned, distributed as $100, $50, $25, and $25. Fig. 3 shows a screenshot of the Top 4 leaderboard used in the training platform.

To evaluate the course design and implementation, several sources of evidence were collected for the purpose to examine how the course design functioned in practice. These materials were interpreted through a descriptive evaluation approach focused on student perceptions, platform usage patterns, and implementation lessons. The purpose of the evaluation was to understand how students responded to the gamification design in an authentic instructional setting and to document preliminary lessons from the implementation. Given the small class size and the practice-oriented nature of the project, the analysis emphasizes descriptive interpretation rather than causal inference or formal hypothesis testing.

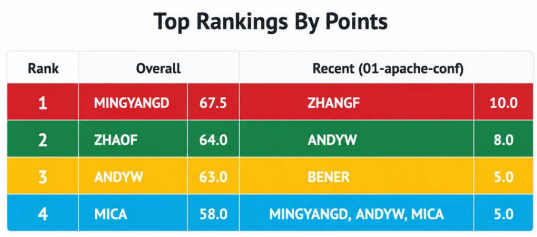


Fig. 3. Leaderboard of Top 4 performers example.

IV. Evaluation Method

A. Evaluation Context and Respondent Groups

To examine students' responses to the gamification design, two respondent groups were included in the evaluation. The first was the pilot cohort of eight students who directly participated in the course and experienced the platform during the implementation period. Their responses constitute the primary classroom-based perception data in this study. The second was a supplementary scenario-based survey with thirty-four students who did not participate in the course. The respondents were presented with a structured description of the course design, including the two instructional phases, the Top 4 ranking display, weekly points emails, badges, gift card rewards, and team-based in-class tasks. They were then asked to report their perceptions using parallel survey items. The purpose of this supplementary survey was not to measure actual behavior or learning outcomes, but to examine how a broader student audience might perceive the course design. Accordingly, these responses are analyzed descriptively and are used only as secondary and supportive evidence.

B. Data Sources

Four sources of evidence were used in the evaluation. First, the pilot student survey collected Likert-style and

open-ended responses about the major gamification features, including points, Top 4 ranking displays, badges, and gift card rewards. Second, the supplementary scenario-based survey collected perception-based responses from non-participating students after they reviewed the course design. Third, platform activity records were analyzed descriptively to identify participation patterns and support the interpretation of the survey results. Fourth, instructor reflections were informed by oral team presentations and informal one-on-one conversations with students during and after the course. These interactions provided additional context for understanding how students experienced the platform and interpreted specific gamification features. Because these conversations were informal and were not analyzed as a formal interview dataset, they are used only as supplementary contextual evidence.

C. Survey Design

The survey instrument was developed specifically for this course design study. Items were constructed to correspond to the main gamification mechanisms embedded in the course: points, public Top 4 ranking, badges, and gift card rewards. Additional open-ended questions invited students to comment on team assignment practices and other aspects of the design. The pilot survey and the supplementary scenario-based survey used parallel core items so that the general pattern of responses could be compared cautiously across the two groups.

Because the survey was intended for exploratory instructional feedback rather than psychometric scale development, the results were interpreted at the item level. The survey was designed to examine several practical questions relevant to the course design, including whether the public Top 4 ranking was perceived as motivating, whether points were viewed as useful for progress tracking, whether badges and gift card rewards attracted student interest, and whether the ranking system was viewed as achievable and fair. Table 2 summarizes the survey items and their intended evaluation purposes. To reduce potential ordering effects and patterned responses, the survey items were intentionally shuffled.

College students majoring in Information Technology (IT) and cybersecurity were recruited to take the survey. A total of 34 valid responses were collected over a two-week period.

The survey data were analyzed descriptively at the item level. Responses were summarized using frequencies and percentages to show how students perceived different gamification elements. Open-ended comments were used to clarify selected response patterns.

Table 2. Survey questions and intended evaluation purposes

#	Question	Purpose	Gamification Category
0	Demographic information including major and academic year	Common factors of information.	NA
1	Seeing the Top 4 rank on the lab wall makes me feel that I want to spend more time on this.	Ranking display → motivation	Ranking
2	Seeing the Top 4 rank on the lab wall DID make me spend more time on this.	Ranking display → efforts	Ranking
3	Instead of on the lab wall displaying the Top 4 rank, I prefer personal emails.	Public display → concerns on internal competition	Published ranking
4	The weekly email of my current points earned is helpful to keep me on track.	Points → quantitative feedback	Points
5	I am interested in winning the Top Know-How Badge.	Badge → motivation	Badge
6	I am interested in winning the Top Communication badge.	Badge → motivation	Badge
7	I am interested in winning the gift card rewards ($100, $50, $25, and $25 for the final Top 4 performers).	Gift card → motivation	Gift card
8	I feel that everybody can make it to the Top 4 rank if they spend enough time on this.	Program design effectiveness. achievable goal	Achievable ranking
9	I feel more motivated when finishing tasks are associated with earning points.	Points → objective feedback	Points
10	I feel more on track to my learning outcome when the points are assigned to each task.	Points → progress tracking	Points
11	I will feel proud of myself if I make it to the Top 4.	Ranking → motivation	Ranking
12	Displaying the Current Week Top 4 along with the overall Top 4 makes me feel that the teacher values continuous improvements.	Clear goal Rank display → motivation Rank display → progress tracking	Ranking
13	Displaying the Current Week Top 4 along with the overall Top 4 makes me feel that everyone can win if they work hard.	Rank display → achievable goal	Achievable ranking
14	I feel my learning outcome is better because of the points, badge, ranking and gift card rewards offer.	G → perceived learning outcome	Overall
15	What do you think about randomly assigning team members each time in the injection sessions?	Team skill training effectiveness	Open question
16	Do you like the random team member approach, or do you prefer a fixed set of team members instead? Why?	Preference of team skill training method	Open question
17	Any other feedback, comments & ideas on using Points, Badge, Ranking in the training sessions? (Your input is very valuable in improving the training sessions)	Special feedback on G	Open question
18	Your comments & feedback on using gift card rewards? (Your input is very valuable in improving the training sessions)	Special feedback on monetary rewards	Open question

D. Data Analysis Approach

The analysis followed a complementary descriptive strategy. First, the pilot survey was treated as the primary source for understanding how students who experienced the course perceived the major gamification features. Second, the supplementary scenario-based survey was used to examine whether a similar pattern of responses appeared in a broader student group. Third, platform activity records were used only as contextual indicators of participation patterns across

the two instructional phases and not as direct evidence of learning outcomes. Fourth, instructor reflections were then used as additional evidence to help interpret the survey findings.

Survey responses were summarized using item-level frequencies and percentages. Open-ended comments were used selectively to help interpret response patterns when relevant. The activity logs were reported as descriptive indicators such as active days, total sessions, total logged hours, sessions per active day, and hours per active day. Because the two instructional phases differed not only in gamification design but also in task structure and the use of shared team accounts, the activity log comparison is interpreted cautiously as a description of overall platform use rather than as evidence of causal impact. Similarly, instructor reflections are used only to provide contextual insight and are not presented as systematically coded qualitative findings.

V. Results and Discussion

A. Survey Results

Because of the limited physical space of the training lab where this course was implemented, the first NCCDC training cohort included eight students. Table 3 reports the item-level response frequencies for the major gamification features, including ranking, points, badges, and gift card rewards.

Table 3. Student perceptions of gamification features (n = 8)[1]

#	Question	L1	L2	L3	L4	L5	Category
1	Seeing the Top 4 rank on the lab wall makes me feel that I want to spend more time on this.	0	0	1	7	0	Ranking
2	Seeing the Top 4 rank on the lab wall did make me spend more time on this.	0	0	4	4	0	Ranking
11	I will feel proud of myself if I make it to the Top 4.	0	0	0	4	4	Ranking
12	Displaying the Current Week Top 4 along with the overall Top 4 makes me feel that the teacher values continuous improvement.	0	1	0	4	3	Ranking
3	Instead of displaying the Top 4 rank on the lab wall, I prefer personal emails.	0	2	3	3	0	Published ranking
8	I feel that everybody can make it to the Top 4 rank if they spend enough time on this.	0	0	0	4	4	Achievable ranking
13	Displaying the Current Week Top 4 along with the overall Top 4 makes me feel that everyone can win if they work hard.	0	0	1	6	1	Achievable ranking
4	The weekly email of my current points earned is helpful to keep me on track.	0	0	1	6	1	Points
9	I feel more motivated when finishing tasks are associated with earning points.	0	0	4	4	0	Points
10	I feel more on track to my learning outcome when points are assigned to each task.	0	0	2	6	0	Points
5	I am interested in winning the Top Know-How badge.	0	0	3	5	0	Badge
6	I am interested in winning the Top Communication badge.	0	0	2	6	0	Badge
7	I am interested in winning the gift card rewards ($100, $50, $25, and $25 to final Top 4 performers).	0	0	0	7	1	Gift card
14	I feel my learning outcome is better because of the points, badges, ranking, and gift card rewards offered.	0	0	4	3	1	All

[1] Likert Scale from L1 (strongly disagree) to L5 (strongly agree). The numbers in the table indicate the frequency of response.

The ranking-related items indicated generally positive perceptions of the Top 4 display. For Q1, seven of eight students agreed that seeing the Top 4 on the lab wall made them want to spend more time on the training, while one student selected a neutral response. At the same time, responses to Q2 were mixed: four students agreed that the display made them spend more time, whereas four students selected a neutral response.

The other ranking-related items showed a similar pattern. For Q11, all eight students responded positively, with four agreeing and four strongly agreeing that they would feel proud if they made it into the Top 4. For Q12, seven of eight students responded positively, suggesting that the combination of the weekly and overall Top 4 displays may have put an emphasis on continuous improvement.

Preferences for public versus private feedback were not uniform. In response to Q3, three students preferred personal emails over public display, two students disagreed with that preference, and three students selected a neutral response. Rather than indicating a strong group-wide aversion to competition, this pattern more cautiously suggests that some students may have been more comfortable with private progress-related communication than with publicly displayed rankings.

The responses to Q8 and Q13 indicate that the Top 4 ranking was generally perceived as achievable. For Q8, all eight students agreed or strongly agreed that anyone could make it into the Top 4, if they spent enough time on the training. Similarly, for Q13, seven of eight students responded positively, and one student selected a neutral response.

The points-related survey item results suggest that points were especially useful for tracking progress, even if their motivational force appeared weaker than that of the public ranking. For Q4, seven of eight students agreed or strongly agreed that the weekly email of points earned helped them remain on track. For Q10, six students agreed that assigning points helped them remain aligned with their learning goals, while two responded neutrally. In contrast, responses to Q9 were evenly split, with four students agreeing that points were motivating, and four students selecting a neutral response.

Student responses to the badge items were also generally positive. For Q5, five students agreed that they were interested in winning the Top Know-How badge, while three students provided a neutral response. For Q6, six students agreed that they were interested in winning the Top Communication badge, and two students selected a neutral response.

The gift card item received the strongest positive response in the survey. For Q7, seven students agreed, and one student strongly agreed that they were interested in winning the gift

card rewards.

Finally, the overall perception item Q14 should be interpreted cautiously. Four students selected neutral responses, three students agreed, and one student strongly agreed that their learning outcomes were better because of the combined gamification design. Rather than indicating a clearly positive consensus, this pattern suggests a more mixed perception: students were more confident in the motivational and engagement-related value of individual gamification features than in making strong claims about improved learning outcomes.

B. Supplementary Scenario-Based Survey

To provide additional context beyond the pilot cohort, the authors conducted a supplementary scenario-based survey with 34 undergraduate students who did not participate in the course. Those students were asked to evaluate the course design after reading a structured description of its primary features. Table 4 presents a portion of the results, while Table 5 summarizes the respondents' demographic characteristics. Most respondents were IT majors (29 of 34), and most were junior- or senior-level students (26 of 34). In addition, 25 respondents rated their IT and cybersecurity knowledge as intermediate or advanced. The supplementary results showed a pattern consistent with the pilot survey. For example, 25 of 34 respondents agreed or strongly agreed that seeing the Top 4 ranking would make them want to spend more time on the course, and 22 of 34 agreed or strongly agreed that it would most likely increase their effort. Similarly, 28 of 34 respondents agreed or strongly agreed that weekly points emails would help keep them on track, suggesting that the points system may be perceived more as a progress-tracking mechanism than as a standalone motivator.

Table 4. Selected results from the supplementary scenario-based survey (n = 34)

Item	Positive Responses/Total
Top 4 ranking would make me want to spend more time on the course	25/34
Top 4 ranking would most likely increase my effort	22/34
Weekly points emails would help keep me on track	28/34
Interested in gift card rewards	27/34
I would feel proud if I made the Top 4	30/33[1]
Learning outcome would be better because of the combined gamification design	21/34

[1]One invalid response received for this question.

Perceptions of badges were moderately positive. 19 respondents expressed interest in the Top Know-How badge, while 15 were neutral or negative. For the Top Communication badge, 15 respondents expressed interest, whereas 19 were neutral. By comparison, the gift card rewards received stronger support, with 27 of 34 respondents indicating positive interest. Public recognition also appeared salient: 30 of 33 valid respondents agreed or strongly agreed that they would feel proud if they made the Top 4. At the same time, responses were more cautious for the broad learning-outcome item. Although 21 of 34 respondents agreed or strongly agreed that their learning outcomes would be better because of the combined gamification design, 9 selected a neutral response and 4 responded negatively. This pattern resembles the pilot survey results, in which students expressed support for the motivational and engagement-related role of individual gamification features rather than making strong claims about improved learning outcomes.

Table 5. Respondent demographics (N = 34)

Variable	Category	N (34)	%
Knowledge	Intermediate	18	52.9
	Beginner	8	23.5
	Advanced	7	20.6
	Novice	1	2.9
Gender	Male	18	52.9
	Female	15	44.1
	Missing	1	2.9
Age	18–24	20	58.8
	25–34	10	29.4
	35–44	3	8.8
	45–54	1	2.9
Major	IT	29	85.3
	Data Analytics	2	5.9
	Cybersecurity	1	2.9
	General Business	1	2.9
Grade	Senior	14	41.2
	Junior	12	35.3
	Freshman	7	20.6
	Sophomore	1	2.9

Responses to the public-versus-private ranking item were mixed. Eleven respondents preferred personal email over public display, 16 selected a neutral response, and 7 disagreed. This pattern further supports the interpretation that public ranking may motivate many students but may not be equally preferred by all students.

C. Activity Log-based Usage Patterns

To complement the survey findings, the authors conducted a descriptive log analysis of platform activity records across the two instructional phases. Table 6 reports the overall platform activity records for the two phases. Phase 1 spanned 57 calendar days (April 12 to June 7, 2024) and was conducted without public ranking, badges, or gift card rewards, although individual point-based feedback was already used for progress tracking. Phase 2 spanned 71 calendar days (August 23 to November 1, 2024) and incorporated the gamified design.

Table 6. Descriptive comparison of overall platform activity across instructional phases

Metric	Phase 1 (Apr. 12–Jun. 7)	Phase 2 (Aug. 23–Nov. 1)
Calendar span (days)	57	71
Active days	31	35
Total sessions	883	1130
Total logged hours	204.4	253.1
Sessions per active day	28.5	32.3
Hours per active day	6.59	7.23

Notes: Phase 2 includes both individual accounts and two shared team accounts used by student groups. Accordingly, the comparison is intended to describe overall platform activity across phases rather than strictly comparable to individual-level usage.

At the overall platform level, Phase 1 recorded 883 sessions across 31 active days, totaling 204.4 logged hours. Phase 2 recorded 1130 sessions across 35 active days, totaling 253.1 logged hours. Standardized by active day, this corresponded to an increase from 28.5 to 32.3 sessions per active day and from 6.59 to 7.23 hours per active day. These descriptive patterns suggested that platform activity was higher during the gamified phase. At the same time, this phase-level comparison should be interpreted carefully. In

addition to individual accounts, Phase 2 included two shared team accounts used by student groups. As a result, the observed increase reflected overall platform activity during the second phase rather than a purely individual-level change in usage. This was consistent with the collaborative structure of Phase 2, which emphasized coordinated team responses in addition to individual technical work.

Overall, the activity log data indicate that the gamified phase was associated with higher platform activity. However, the log analysis should not be interpreted as evidence that gamification alone caused the increase. The two phases differed not only in gamification design but also in task structure, collaboration requirements, and account usage. For this reason, the log data is best understood as contextual indicators of how the course operates across phases rather than as direct evidence of improved engagement or learning effectiveness.

D. Instructor Reflections and Informal Student Feedback

Instructor reflections and informal student feedback provide additional context for interpreting survey and log patterns. First, the instructor observed that students appeared to complete their assignments in a more timely and consistent manner after the Top 4 leaderboard was introduced. Second, the system access logs suggested a general increase in platform activity during the gamified phase. Third, oral team presentations helped clarify that logged activity did not always capture the full extent of student effort. In some cases, students with relatively low logged time had nonetheless contributed substantially through planning, coordination, discussion, or other forms of off-system work. Informal one-on-one conversations with students also yielded generally positive feedback about the platform, particularly regarding its role in making progress more visible and sustaining attention during the course. These reflections were used only as informal contextual evidence that helped interpret the descriptive survey and usage patterns.

E. Discussion

The survey findings indicate that public ranking was perceived as motivating, although its perceived effect on actual student effort was more moderate. The weekly and overall Top 4 rankings appeared to encourage continuous improvement, while mixed responses regarding personal emails versus public display suggest that multiple feedback channels may better support different student preferences. These findings address RQ2 by suggesting that rankings, points, badges, and rewards can enhance student engagement and participation, consistent with prior gamification studies such as Refs. [7, 10].

Students also perceived the Top 4 ranking as achievable, which may help maintain its motivational value. Points functioned mainly as a progress-monitoring mechanism, while badges received moderate support and gift card rewards were viewed most positively. Together, these findings suggest that combining multiple gamification mechanisms is more effective than relying on a single incentive, which is consistent with prior research findings in Ref. [8].

The supplementary survey showed a similar pattern, with respondents favoring gamification features that increased visibility, recognition, and progress tracking. These results support RQ1 by indicating that an instructor-controlled platform integrated with structured gamification is a practical design for experiential cyber-defense training.

The activity logs suggest higher platform activity during the gamified phase, although differences in task structure limit direct comparison. Similarly, instructor reflections provide contextual rather than causal evidence. These observations provide preliminary support for RQ3, suggesting that the two-phase structure facilitated both technical skill development and team-based collaboration, consistent with prior research on experiential cybersecurity education [1, 2]. For instructors, the findings suggest that a customizable, low-cost platform with integrated gamification offers a practical alternative to more expensive commercial training environments.

VI. Conclusion

This paper presents the design and classroom implementation of a self-built gamified platform for NCCDC-oriented cyber-defense education. By integrating points, rankings, badges, and small tangible rewards, the platform provides a low-cost, instructor-controlled approach that supports course customization and aligns gamification mechanisms with specific instructional objectives.

The exploratory evaluation indicates generally positive perceptions of the proposed design. Students viewed public rankings as motivating and points as effective for tracking progress, while badges and gift card rewards were also viewed positively. The supplementary survey and instructor observations showed similar patterns, suggesting that visible recognition and structured feedback may enhance student engagement. At the same time, some participants preferred private feedback, highlighting the importance of balancing competitive and individualized motivational strategies.

The proposed platform demonstrates that instructors can develop and deploy a low-cost, customizable cyber-defense training environment without relying on commercial platforms or extensive institutional infrastructure. The platform offers a practical framework for integrating hands-on training, staged instructional activities, and gamification into cybersecurity courses, while allowing instructors to adapt game mechanics and learning activities to their own teaching objectives. These findings provide practical guidance for educators seeking flexible and sustainable approaches to experiential cybersecurity education.

The primary contribution of this work is a practice-oriented framework demonstrating how a self-built gamified cyber-defense platform can be designed and deployed in a resource-constrained educational setting. Because the study involved a small pilot cohort and relied on supplementary scenario-based data and descriptive observations, the findings should be interpreted as exploratory. Future research should further investigate the effectiveness of the staged course design and the effects of integrated gamification on student engagement and learning outcomes.

Conflict of Interest

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Dr. Xiang Guo, Dr. Zhiguo Yang, and Dr. Zongxi Liu contributed to the conceptualization and design of the study. Dr. Zhiguo Yang and Dr. Zongxi Liu conducted the data collection and analysis and interpreted the results. Dr. Xiang Guo and Dr. Zongxi Liu contributed to the preparation and revision of the manuscript. Dr. Zhiguo Yang wrote the original draft of the manuscript. Dr. Zongxi Liu led the development of the research platform and course. All authors reviewed and approved the final version of the manuscript.

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