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Battlespace Next™: Developing a Serious Game to Explore Multi-Domain Operations

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Abstract

Changes in the geopolitical landscape and increasing technological complexity have prompted the U.S. Military to coin the terms Multi-Domain Operations (MDO) and Joint All-Domain Command and Control (JADC2) as over-arching strategy to frame the complexity of warfare across both traditional and emerging warfighting domains. Teaching new concepts associated with these terms requires both innovation as well as distinct education and training tools in order to realize the cultural change advocated by senior military leaders. Battlespace Next™ (BSN) is a serious game designed to teach concepts integral to MDO and initiate discussion on military strategy while conserving time, money, and manpower. BSN, a Collectable Card Game (CCG), is engineered to provide an engaging learning tool that educates on capabilities in a multi-domain conflict. This paper proposes an extensible game framework for modeling and reasoning about MDO concepts and presents our empirical feedback from over 120 military play testers evaluating a moderate to difficult version of the game. Results reveal the game teaches MDO concepts and delivers an engaging, hands-on learning experience. Specifically, we provide evidence it improved military readiness in seven areas of MDO in at least 62% of participants and 76% of respondents reported they enjoyed playing the game.

Keywords: Serious Games, Multi-Domain Operations, Military Education and Training

1 Introduction

In response to an increasingly complex battlespace, the U.S. Air Force (USAF) and other U.S. Military branches are seeking to improve education and training to produce a workforce able to adapt and respond in an environment characterized by the intersection of traditional and emerging warfighting domains. Inducing this transformation requires appropriate learning tools that are accessible to educators, effectively teach Multi-Domain Operations (MDO) concepts, and engage personnel. Many challenges exist in MDO education, most notably the complexity of the material and the breadth of career fields that require it [1]. These challenges are exacerbated by the lack of innovation and consensus of how MDO concepts will operate in future conflicts. Significant education and training are often required before operators exhibit depth of knowledge and skill in just one domain, but now strategists and operators will require

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proficiency in multiple, complex domains to both plan and execute operations that integrate breadth and depth at the intense speed required for victory.

To meet these challenges, this article proposes a serious game framework designed around relevant Learning Objectives (LOs) seeking to reveal synergy between military capabilities as well as challenge learners to innovate by creating their own strategies for victory. The LOs address the integration of cyber capabilities, the spectrum of conflict, and strategy development in the midst of a complex and contested environment. The proposed framework is modeled after successful Collectable Card Games (CCG) where each player must choose specific cards to purchase, deploy, and utilize for offensive and defensive actions against an opponent with the ultimate goal of eliminating them from the game.

In order to evaluate the proposed game framework, a human subjects research (HSR) study was undertaken to answer the following research questions (RQ):

RQ1. What is the response to a serious game in military education and training courses?
RQ2. To what extent does the game framework model and teach current MDO concepts?
RQ3. What effect does this particular game have on players?
RQ4. How time-efficient is course integration?
RQ5. To what extent does the game framework facilitate MDO innovation?

The HSR study explores the effectiveness of the serious game and the efficiency of integration into current military courses. Additionally, play testing collected feedback from players, MDO experts, and military leaders currently shaping the MDO discussion. The results help shape detailed answers to RQ1-RQ4 and offer insight on RQ5.

The layout of this paper is described as follows. Section 2 discusses the nature of MDO and provides a brief overview of serious games and wargaming. Section 3 describes the game system used in BSN, the major changes made during game development, the LOs used in the design process, and proposes a game framework to model MDO. Section 4 details the experiment procedures. Section 5 presents the results from the experiments and analysis of the quantitative and qualitative data. Section 6 discusses the study implications for serious game design as well as current and future MDO learning. Finally, section 7 draws study conclusions and presents suggestions for future research.

2 Background

The military defines five domains as key warfighting domains: land, maritime, air, space, and cyberspace [2].[1] Increasing the complexity of operations is the rise of Information Operations (IO) impacting both military personnel and civilians as well as Electronic Warfare (EW) capabilities. USAF Chief of Staff, General David Goldfein, states that MDO is "using dominance in one domain or many, blending a few capabilities or many, to create multiple dilemmas for our adversaries [4]." Although this topic remains nebulous, we theorize that recognition of capabilities and their combined effects are necessary, but perhaps insufficient, for teaching MDO. These basic MDO concepts must be accompanied by adaptation, strategy development, knowledge of dependencies, and awareness of non-kinetic integration. All of these concepts are necessary to develop military personnel to make sound decisions in the emerging battlespace characterized by volatility, uncertainty, complexity, and ambiguity (VUCA) a characterization of the global environment first used at the Army War College [5].

Goldfein emphasizes the need to integrate MDO into current curriculum and create numerous hands-on learning opportunities for the force [6]. In order to foster these hands-on

[1]Frequently referred to as just "cyber." Some consider cyber as a part of the larger electromagnetic spectrum (EMS) domain. The human domain is also discussed as a warfighting domain, but not yet defined in joint military doctrine [3].

experiences and deliver comprehensive MDO learning, the military needs education and training resources that are accessible, flexible, and allow for student exploration in order to deliver clarity on the essential character of MDO.

2.1 Serious Games

Serious games are described as games designed for purposes beyond entertainment [7][8]. Abt [9] published *Serious Games* in 1970 describing an idea of pairing the experimentation of play with problems that require careful thought. Current literature surveys [10][11][12] provide a review of empirical evidence for the effects of serious games, which are largely positive. Specifically, serious games are connected to improved knowledge acquisition and content understanding. Additionally, they are shown to be effective training tools and produce behavioral change in players [13]. One rigorous, controlled experiment follows many best practices and shows the effectiveness of multiple games when compared to more traditional instruction, especially for learning hands-on skills [14]. Another study tested a serious game to train adaptive decision in military personnel [15]

The U.S. Military utilizes serious games for a variety of purposes [16]. Examples include *America's Army*,[2] *Airman Challenge*,[3] World War II Spotter Cards,[4] and playing cards showing modern weapon systems from other countries.[5] The USAF uses digital wargames regularly in accessions training [17] and officer Professional Military Education (PME) [18]. *CyberCIEGE*, created at the Naval Postgraduate School, is a single-player cybersecurity simulation [19]. Long and Mulch designed *CyberWar 2025*, a multiplayer digital game teaching cyber operations terminology [20]. Two wargames are used in [21] to analyze cyber operations in conflict. Additionally, a game teaching computer networking to ROTC cadets at the Air Force Institute of Technology (AFIT) is detailed in this unpublished article [22].

2.2 Wargames and Serious Games

Wargames are impacting training, education, and research in both military and, more recently, non-military contexts [23]. Wargames are used to build understanding of a specific scenario or problem set. One military organization defines wargaming as "a tool for exploring and informing human decision-making [24]." Many levels of wargames are used in the military today encompassing table top exercises to National and Combatant Command exercises involving multiple global and regional commands [25]. Currently, the USAF is focused on wargaming to induce MDO exploration and hands-on learning. The primary example is the Doolittle Wargames, an annual event focused on JADC2 [26]. These wargames are essential to shape future military strategies but time, money, and expertise prohibit their use on a larger scale for MDO education. One Army wargame expert said that major wargames can cost $100,000 to $1 million and require months of planning and hundreds of man-hours.

3 The Game Framework

BSN was created to address the need for engaging and accessible learning tools while modeling MDO interactions and enabling exploration of MDO concepts. BSN draws heavily from

[2]https://www.goarmy.com/downloads/americas-army-game.html
[3]https://www.airforce.com/airmanchallenge
[4]https://store.nationalww2museum.org/wwii-airplane-spotter-player-cards.html
[5]https://www.military.com/daily-news/2019/11/15/army-using-playing-cards-train-soldiers-enemy-weapons.html

the Multi-Domain Command and Control Trading Card Game (MDC2 TCG), an original serious game created by Dr. Alan Lin in 2018 [27]. Both games use the same framework and share several elements and characteristics.

3.1 Game Learning Objectives

LOs were used during development as detailed in Table 1. Each is identified with a specific level of Bloom's Taxonomy of Learning to help instructors identify how they game might meet their academic goals and tailor to student experience levels.

Table 1: *Definition of Game LOs with Associated Bloom's Taxonomy Level*

Learning Objective	**Level of Bloom's Taxonomy of Learning**
Recognize that both cyber and kinetic capabilities require a kill chain and advanced planning	Knowledge (Level 1)
Match cyber defense capabilities to corresponding threats	Comprehension (Level 2)
Recognize the two levels on the Spectrum of Conflict (competition and conflict) and practice using appropriate assets within each	Comprehension (Level 2)
Develop and execute an MDO strategy in a complex and contested environment	Synthesis (Level 5)
Select and combine capabilities to anticipate, adapt, and respond to surprise and uncertainty in near-peer warfare	Evaluation (Level 6)

3.2 Collectable Card Game Genre

The game design is drawn from commercially successful games in the CCG genre, such as *Hearthstone*,[6] *Magic the Gathering (MtG)*,[7] and *Pokémon TCG*.[8] *Cyber Threat Defender*,[9] another serious game, also influenced the design. In particular, *Hearthstone* has been the topic of recent research applying Artificial Intelligence (AI) research to create capable autonomous agents [28][29].

Järvinen [30] and other game description frameworks, such as [31], use *mechanics* to categorize games. A game mechanic is a game feature that a player can interact with toward a specified end goal. The core mechanic of CCGs is "arranging and choosing," which refers to the organization of the cards and the order they are played. The primary modifier mechanic, "attacking and defending," changes the state of the game as players use cards to affect their opponent.

Järvinen identifies *sequential reasoning* and *induction* as the key abilities required to excel at CCGs. Sequential reasoning is needed to order cards and capabilities to create effects. Players who know the ability of each card and play it at the appropriate time will excel. Induction is defined as the process of deducing rules or other common characteristics underlying a given set of stimulus materials. In the game, players must identify winning combinations both at the beginning of the game (during strategy development) and subsequently during game play as they draw cards from their randomized supply pile. In summary, the CCG game genre requires players to use sequential reasoning and induction to arrange and choose cards to outplay their opponent and eventually eliminate them from the game through offensive and defensive actions.

[6] https://playhearthstone.com/en-us
[7] https://magic.wizards.com/en/mtgo
[8] https://www.pokemon.com/us/pokemontcg
[9] https://cias.utsa.edu/ctd.php

Therefore, to partially answer RQ2, this game genre models MDO concepts and relationships. First, the cards provide a tangible method of distilling military capabilities and weapon systems into maneuverable assets within the game. Students can control and combine assets in numerous ways revealing how capabilities from multiple domains create synergistic effects while challenging them to develop new and innovative combinations. The player selects 6 cards from the 48 available for strategy development leading to over 12 million possible starting hand combinations. Second, the primary goal of each country in peer warfare is to out-maneuver (outplay) the other country in order to eliminate their ability to wage warfare. Therefore, this game system creates a similar win condition to MDO scenarios, such as the one proposed by Goldfein [4]. Finally, military strategists require sequential reasoning to develop effective strategies and execute operations. As a player orients to the operational environment created by the game and combats an opponent, he or she is exercising the skills and competencies required for military operations planning. All of these aspects blend together to make the game useful for modeling MDO warfare and developing competencies in military personnel.

3.3 Multi-Domain Command and Control Trading Card Game

MDC2 TCG is a 2-player CCG featuring military capabilities from air, cyber, ground, and space domains. Each player chooses from 59 cards to build a deck of 40 cards to wield against an opponent, who are both seeking to reduce the other's health points from 20 to zero. Kinetic capabilities, such as ground units and bombers, can strike the opposing player to remove heath points. Players can also group air and ground capabilities into force packages to create desired effects and counter enemy offensive and defensive actions. The game is focused on the integration of cyber attack and defense capabilities into warfare. Cyber capabilities follow a simplified version of the cyber kill chain first proposed by Lockheed Martin [32] including reconnaissance, gaining access, and exploitation. Three examples of cyber capabilities are included in Figure 1. Particular attention was placed on the cyber capabilities and their application as this domain is often least understood by military personnel.

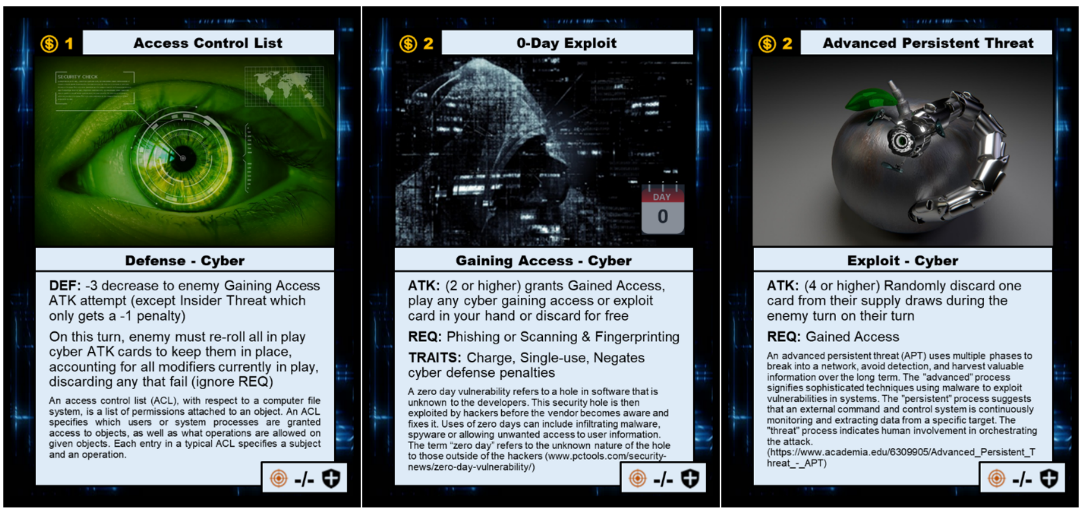

Figure 1: *Examples of Cyber Capabilities in MDC2 TCG*

3.4 Battlespace Next™

BSN uses a similar card format and basic game design and was engineered for greater effectiveness based on play testing, subject matter expert (SME) interaction,[10] and experiment feedback. A robust description of the game rules, card formats, and experiment procedures can be found in [33] and [34]. The major changes include:

1. Removal of the deck-building phase to reduce start-up time and limit the amount of cards required to play. This change reduced the initial decision space for players as they learn game mechanics to help integrate into tight course schedules and lower the cost of printing new game decks.
2. The addition of new cards representing capabilities across all warfighting domains, including human. BSN includes more Space cards, Maritime assets, and Information Operations (IO) and Electronic Warfare (EW) capabilities. IO capabilities represent capabilities leveraging information to manipulate the human domain. BSN uses 25 cards from the original game and adds 29 new cards, based on feedback.
3. A Multi-Domain Operations Center (MDOC) was added to represent current terminology in USAF future operating concepts [26]. This change included a deliberate shift in the game's objective, as players seek to destroy their opponent's MDOC instead of the player themselves. This was easier for players to grasp leading to fewer questions. This card and other game elements are shown in Figure 2.
4. The Spectrum of Conflict mechanic was added to represent the difference between conflict and competition[11] in near-peer warfare and regulate the beginning of the game. This changed directly supported LO 3 in Table 1.

Figure 2: *Examples BSN Game Resources and Cards. From left to right: game supplies; an example of a Maritime capability; the MDOC card (each player starts with this card)*

3.5 Game Framework

BSN is part of a larger framework designed to model and teach MDO. The framework has three levels:
(1) Intro Game. A version of BSN with simplified instructions designed to teach the basics of the game using 20 cards (2-3 from each domain). Although not implemented in this study due to time constraints, this level could be used by instructors to expose students to BSN for familiarization.

[10] The authors provided expertise on cyber and IO capabilities, two additional SMEs contributed to the Electronic Warfare assets, and three SMEs provided input on space related capabilities.
[11] Additional information located here: https://www.jcs.mil/Portals/36/Documents/Doctrine/concepts/joint-concept-integrated-campaign.pdf

(2) Target Game. This level describes versions of the game in the moderate to difficult category, designed to go beyond an introduction, but can be learned and played in under 4 hours. BSN is designed to serve as the primary, and most general, version on this level. This level also includes scenarios that introduce specific rules or capabilities to emphasize a particular LO. For example, nuclear capabilities could be introduced to explore how players react during and following a nuclear event.
(3) Meta Game. This level would introduce many more cards, including capabilities from near-peer adversaries, to deeply explore emerging technologies and military strategy. At this level, each player must build a deck of 48 cards from all available options.

The advantages of this framework is that it uses the same cards across all levels, unless specifically excluded to meet specific LOs. This encourages the addition of new cards from a variety of sources with one integrator for consistency and game balance. Additionally, the framework allows for various levels of engagement with the game from beginners to experienced players, providing sufficient challenge for all. This establishes a path to long-term intervention which is linked to long-term behavioral change [13].

4 Procedures

To evaluate the research questions, investigators completed six HSR experiments[12] testing the effect of the game and course integration efficiency. The research methodology followed best practices identified by [35] and [36], although some departures were necessary based on environment constraints. The study was conducted over a period of 13 months reaching a total of 160 participants in formal education settings. 83 (51.8%) participants completed both surveys. A pilot study, consisting of 58 participants helped shape the experiment procedures and data collection tools.[13] A summary of the pilot study and primary study experiments is shown in Table 2 .

Each experiment followed this basic procedure:

(1) Deliver outline of experiment procedures and send pre-survey.
(2) Distribute game resources and provide instructions for in-class session.
(3) Conduct in-class session where all students play the game for at least one hour and participate in a group debriefing.
(4) Send post-survey to all participants.

These steps are consistent with other serious game studies [38][14][15][22], although most controlled the time spent learning and playing the game, which was an uncontrolled variable in this study.[14]

4.1 Game Evaluation

The study evaluated BSN by collecting instructor and student self-reported learning and game response.[15] Instructors received a 13 question post-survey containing Likert scale and open response questions on their experience. All participants received a 51 question pre-survey and 38 question post-survey to measure the effect of the game on MDO learning and military readiness. Surveys collected participants' self-reported game experience, what they learned, and

[12] Study approved by AFIT's Institutional Review Board and performed in accordance with ethical standards. Protocol Exemption: REN2019018R Reith; Title: Multi-Domain Operations Education and Training Integration Research

[13] Additional information on the pilot study can be found in this unpublished paper [37].

[14] Additional information is included in a thesis expected to be release by AFIT in 2020.

[15] Responses were collected through Limesurvey: https://www.limesurvey.org

Table 2: *Summary of Experiments for Pilot and Primary Studies*

Experiment	Location	Total Players	Participants who Completed Both Surveys	Study Structure	Experiment Duration	Typical Participant Military Experience
Pilot A (Oct '18)	Air Force Institute of Technology - Cyber Warfare and Security Course	14	12 (86%)	Instructor (co-author) led experiment and debriefing	1 Hour & 50 Minutes	Primarily junior AF officers
Pilot B (Feb '19)	Training Seminar at the Rocky Mountain Cyberspace Symposium in Colorado Springs, CO	44	28 (63%)	Session organized and led by author and participants volunteered to participate in training	2 Hours	Mix of DoD military, contractors, and civilians with varied levels of experience
Total		**58**	**40 (69%)**			
1 (Jul '19)	13O (MDC2 Career Field) Initial Skills Training, Hurlburt Field, FL.	27	15 (55%)	Author invited to lead in-class session with involvement from course instructors	2 Hours & 15 Minutes	Primarily AF Officers (O-4s and O-5s) with 6-15 years of experience
2 (Jul '19)	Advanced Cyber Training (ACE) - Reserve Officer Training Corps (ROTC) cadet summer training program	36	9 (25%)	Requested volunteers to participate in experiment during four lunch periods.	3 Hours (split over 4 days)	College students in their Junior year enrolled in Army or AF ROTC.
3 (Aug '19)	Air Command and Staff College (ACSC) - Multi-Domain Operations Strategist (MDOS) Program	45	21 (47%)	Participants split into four seminars. Two played MDC2 TCG and two played BSN	2 Hours & 30 Minutes (split over 3 days)	AF and Joint officers (O-4s) with 14 years average military experience
4 (Oct '19)	Air Force Institute of Technology - Agile Software Engineering Master's Course (SENG 593)	23	18 (78%)	Participants played two games in just under 1 hour, no group finished their game	1 Hour & 30 Minutes (split over 2 days)	AF active duty and DoD Civilian students with limited operational experience
5 (Nov '19)	Air Force Institute of Technology - Cyber Warfare and Security Master's Course (CSCE 525)	16	12 (75%)	Participants played in pairs and most finished two full games	2 Hours & 30 Minutes (split over 2 days)	AF Active Duty students enrolled in Graduate Cyber Program
6 (Nov '19)	Army Reserve Officer Training Corps (ROTC) - Wright State University	13	8 (62%)	Requested volunteers to participant in 1 of 2 experiment sessions	2 Hours & 15 Minutes	College students, most with limited military experience
Total		**160**	**83 (51.8%)**			

recommended improvements. The surveys included questions linked to the common factors identified by [39] and [40] including enjoyment, motivation, play-ability, usability, realism, relevance to personal interests, and learning effectiveness. Electronic data collection tools were provided outside of both the game and in-class session and were designed to measure participant response and learning instead of providing feedback to the students on their game performance.

Other assessment methods were considered. An objective pre-test and post-test would have been preferred to self-reported learning attainment. However, due to the novelty of the game's subject matter, a standardized assessment was not available. In-game data collection was also desired, but the number of concurrent games (up to 20) made individual game observation impossible without significantly increasing the cost of the study.

4.2 Population

MDO education is required for a broad audience so a wide range of experiment populations was desired. This choice drove variability in the data, but also allowed comparison across a wide range of ages, operational experience, and interest in learning about MDO. Experiments were limited to education and training environments in which curriculum owners were willing to use training hours to complete the experiment. This constraint was introduced to motivate student participation and test course integration.

Specific courses were targeted because their course material matched the explicit LOs of the game or the instructors were interested in using the game in future courses. Researchers targeted the 13O Initial Skills Training (IST) to provide feedback from personnel with Command and Control (C2) experience chosen to advance the implementation of MDO in the USAF. 13O IST contained a large cadre of officers with significant operational experience, providing early data on the game's realism. Next, the Advanced Cyber Education (ACE) course provided a large group of students in the 18-24 age group, a common target audience for serious games,[16] without MDO experience. The third experiment at Air Command and Staff College (ACSC) provided a large population where the two major versions of the game could be tested by personnel familiar with MDO concepts. In this study BSN was introduced to validate the development progress by comparing both versions. Experiments four[17] and five[18] tested the game's integration into master's-level courses with a majority of students in the junior officer category, which was recommended by senior leaders as a prime audience. Finally, the Army ROTC experiment tested the improved game version with younger players as well as examined the integration of the game in an officer accessions program, identified as an appropriate target environment for long-term use.

4.3 Data Collection

Data was collected through pre-surveys and post-surveys, both distributed electronically through email. Initially, participant names were used strictly to align both surveys and paper scorecards tracking game outcomes.[19] However, later experiments assigned a random token to participants to align responses. The pre-survey collected demographic data, game habits, and military operational experience. The post-survey queried individuals on their response to the game and growth in readiness. Surveys included questions about the use of general educational games (serious games) to maximize the opportunity to survey military personnel. Several post-survey questions measuring game response were modeled after published game questionnaires [41][42] while other questions measuring improvement in military readiness were modeled after content by the Gaming Research Integration for Learning Laboratory®[20] who frequently experiment with games for military training.

4.4 Environment

Four of the experiments were held in a typical classroom during regular course hours and two required special arrangements. The instructor for the Army ROTC experiment decided to establish a separate time for students to voluntarily participate in the experiment. The primary purpose was to increase participation from all those enrolled in the ROTC program. The ACE schedule limited the experiment to volunteers who committed time to participate over four consecutive lunch periods. In the other four studies, the instructors required all enrolled students to participate in the experiment. In these cases, student attendance was mandatory as it was during a scheduled class period, but survey completion was optional.

4.5 Participant Instructions and Schedule

Participants were given access to the pre-survey electronically through their email and then provided the game resources (instructions, cards, and tutorial video). All participants, except those in the 13O IST experiment, received physical cards and instructions at least two days prior to the in-class session. Participants were instructed to review the resources, develop an initial game strategy, and arrive at the in-class session ready to play. This out-of-class preparation was needed because course instructors would only allow 1.5-2.5 hours of class time for the experiment instead of the 4 hours requested. The post-survey queried participants about the amount of time spent reviewing the game resources outside of class, however experiments

[16] America's Army, which was marketed to high school and college students, is a prime example.

[17] CSCE 525 is a master's course titled "Cyber Warfare and Security" and is taught by the Computer Science and Computer Engineering (CSCE) Department at AFIT.

[18] SENG 593 is a master's course titled "Agile Software Systems Engineering" and is taught by the Systems Engineering and Management (ENV) Department at AFIT.

[19] No participant names or identifying information was included in any data release.

[20] https://gamingresearchintegrationforlearninglab.com

that controlled the exact time allowed for learning and playing the game would likely produce more reliable results. Data showed that it was common for participants to ignore the game preparation tasks. One third of all participants did not review the materials before the in-class session. In order to complete the experiment, students were still expected to play the game during the in-class session instead of taking time from prepared students to teach the game. This forced unprepared students to learn the game while playing. It is assumed that this distracted all students from the primary LOs as the unprepared students were much more focused on the game rules and mechanics than strategy development and real-world implications.

Participants had between 2-6 days to review all resources before the in-class session. The in-class session lasted 1-2.5 hours and allowed participants to play at least one game against a similarly skilled opponent and participate in a group debriefing led by a researcher or course instructor. The first game would serve as a demo game to increase game familiarity. In subsequent games, players are matched to an opponent of similar skill to maintain a high challenge level, which is connected to engagement and learning in serious game experiments [40]. To maintain challenge without frustrating players who did not perform well, participants who won the first game would be paired with another winner and vice versa with the losing players or teams.[21]

4.6 Conditions

The study tested the two games described above. Both served as specific implementations of a Target Game as described by Level 2 of the proposed game framework. The 13O IST and ACE experiments used MDC2 TCG, although slight changes were made to the tutorial video and game instructions between experiments. The ACSC study provided a unique environment due to the number of participants and available classroom space. The class of 45 students was already split into four groups that were evenly distributed by operational experience, gender, and branch of military service. This allowed for a comparison study that was not reproducible in other courses. MDC2 TCG was tested in 2 seminars with a total of 22 students and BSN was used in 2 seminars with a total of 23 students. The remaining experiments (4-6) used BSN, although further changes were made after experiment 3 such as card corrections and simplification. The condition changes, though necessary to create the most quality end product, introduced variability in the experiments that caused uncertainty in the data and limited statistical significance. Changes were made to the game rules, cards, and instructional products, especially in the transition from one game version to the next in experiments 3 and 4.

4.7 Participant Demographics

Table 3 lists the average age and operational experience of all respondents from each experiment. The population Standard Deviation (SD) is provided for individual experiments and the entire study. 78% of participants were USAF personnel (66), the remaining participants were split between Army (10), Department of Defense (DoD) Civilians (5), Coast Guard (1), and Marine Corps (1). The composition of this population was dependent on those who signed up for these courses and no student had a priori knowledge that they would be playing the game.

[21] In experiments 4 and 5 players formed their strategy and played the game in pairs to increase teamwork and cooperation during game sessions.

Table 3: *Participant Age and Years of Operational Experience by Experiment with Standard Deviation (SD)*

Experiment	Average Age (Years)	SD	Average Operational Experience (Years)	SD
13O IST	36.4	3.9	12.9	2.7
ACE	21.2	0.4	1.4	1.7
ACSC	35.5	1.5	13.9	3.1
SENG 593	28.9	5.6	5.9	4.9
CSCE 525	27.7	4.3	6.1	3.8
Army ROTC	21.5	1.4	2.6	1.2
Study (Overall)	30.2	6.6	8.5	5.6

4.8 Research Limitations

The research must be interpreted in light of several limitations. First, variation in environments, duration, game instructions, game resources, and data collection tools may negatively impact the reliability of the data set. This restricted direct comparison across experiments because differences in response could not be solely based on the treatment, except in the ACSC experiment. This led to a greater emphasis on the qualitative aspects of the data. Second, a control group for all experiments was not available to draw direct comparisons. While MDO awareness education is increasing, no standardized training exists that addresses similar LOs, especially related to strategy development and capability awareness. Analysis of quantitative data was tempered by the lack of a control group limiting broader conclusions of the effectiveness of a serious game over other methods. Third, the lead author was highly involved with all the studies and one of the researchers instructed SENG 593,[22] which may have biased participants to inflate game effectiveness, although we find this unlikely because this instructor did not track respondents or responses. Finally, the limited response to both surveys may not be sufficient to demonstrate statically significant results.

5 Results and Analysis

The data collected from both surveys were paired together to compare the participants' self-reported readiness, game usage, demographic data, other factors contributed to post-survey responses. The quantitative data was analyzed for statistical significance based on participant age, weekly game usage, and game version, however, no statistical significance was found. The data provides evidence to answer RQ1-4 and provides insights on RQ5. Survey question nomenclature is based on the order of appearance. "PreQxx" is used for pre-game survey question #xx. The same is used for the post-game survey ("PostQxx").

5.1 [RQ1] What is the Response to a Serious Game in Military Education and Training Courses?

The response to the use of games in military education and training was largely positive. Out of 120 participants, only 5 (4.2%) reported that they do not enjoy learning through games and 7 (5.8%) did not want to see more games used in military education and training. Figure 3 shows the results the following statements using a 5-point Likert scale:
[PreQ48] Formal military education and training needs to be more engaging.

[22] No authors completed participant or instructor surveys.

[PreQ49] I enjoy strategy games.
[PreQ50] I enjoy learning through games.
[PreQ51] I want to see more games used in the military for education and training.

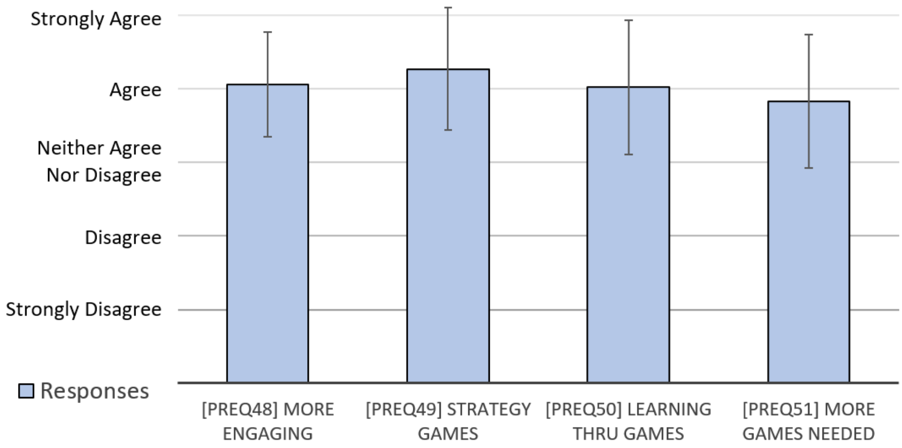

Figure 3: *Participant Response to the Use of Games in Military Education and Training (N=120). Error bars show* ± 1 *SD.*

Participants' enjoyment of games and their desire for more games in formal learning help characterize an individual's response to the use of a game. Figure 4 shows this relationship by comparing responses to PreQ50 and PreQ51. While we expected a strong correlation between these two questions, our results suggest additional factors at work. Although an individual may enjoy educational games they may not always desire to use them in formal learning settings. A group of participants (N=20) enjoy learning through games but were neutral or disagree on their increased use in military education (values highlighted in red). A few (N=6) who were neutral on the enjoyment of games still thought they should be used more often in military education (values highlighted in blue). These results may be partially explained by the broad terminology ("game") used in PreQ51 as the specific game may significantly impact the response.

After experiencing the treatment, participants were asked to compare it to a hypothetical lecture on MDO. 83% of those questioned said they would have rather played the game. A small percentage (2%) would have rather attended a lecture and 15% were undecided. These results show that military educators and curriculum owners will receive a mixed response when implementing a game but a majority will find it valuable. However, mixed response may be common across all learning methods and tools due to the varied desires and interests of students.

5.2 [RQ2] Does the Game Framework Model and Teach Current MDO Concepts?

Section 3.2 explains why the game framework is appropriate to model MDO. In addition, both qualitative and quantitative data revealed the game was well-suited to teach MDO concepts and increase MDO readiness. Specifically, students reported an increased knowledge of capabilities, improved understanding of cyber, and the synergistic effects created by the simultaneous use of capabilities from multiple domains. Qualitative analysis of all post-surveys[23] (N=133) identifies 83 who responded to the question "[PostQ22] What did you learn from this game?" These were analyzed and coded based on the main idea in the response. If a response touched on multiple themes, it was broken into two or more categories. This led to

[23]This includes the pilot study and those who did not complete the pre-survey.

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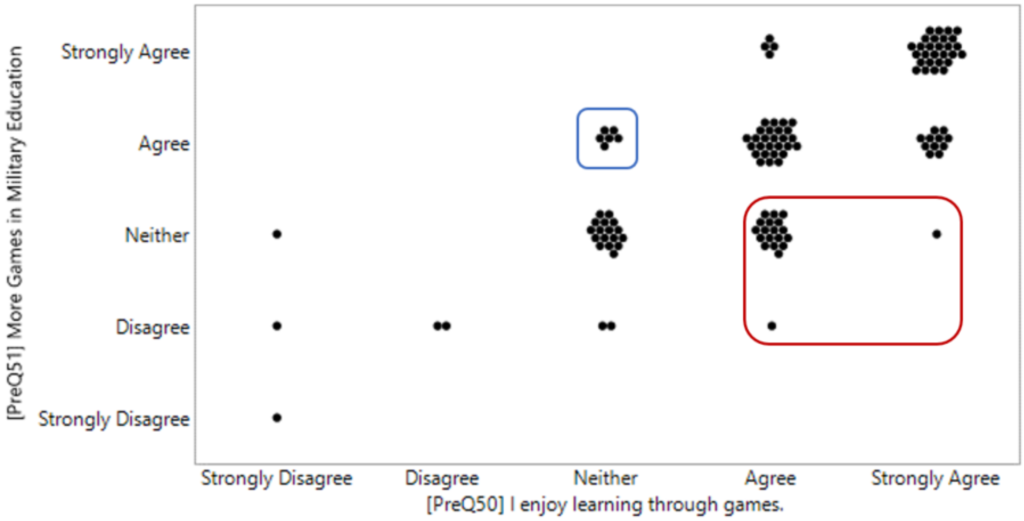

Figure 4: *Comparison of Responses to PreQ50 and PreQ51 (N=120). The red box shows participants who like games but not in formal education. The blue box shows participants who are unsure about educational games but think they should be used in formal training*

117 unique comments, of which 97 were interpreted as positive (38 for MDC2 TCG and 59 for BSN). Figure 5 shows the outcomes by percentage of comments by game version. Twelve negative responses were received, nine for MDC2 TCG and three for BSN. Half of them were addressed by game changes. The remaining comments revealed three participants thought the games were inappropriate to teach MDO, two said capabilities weren't realistic, and one reported they didn't learn anything. Six other participants reported they needed more time to play the game to identify learning outcomes.

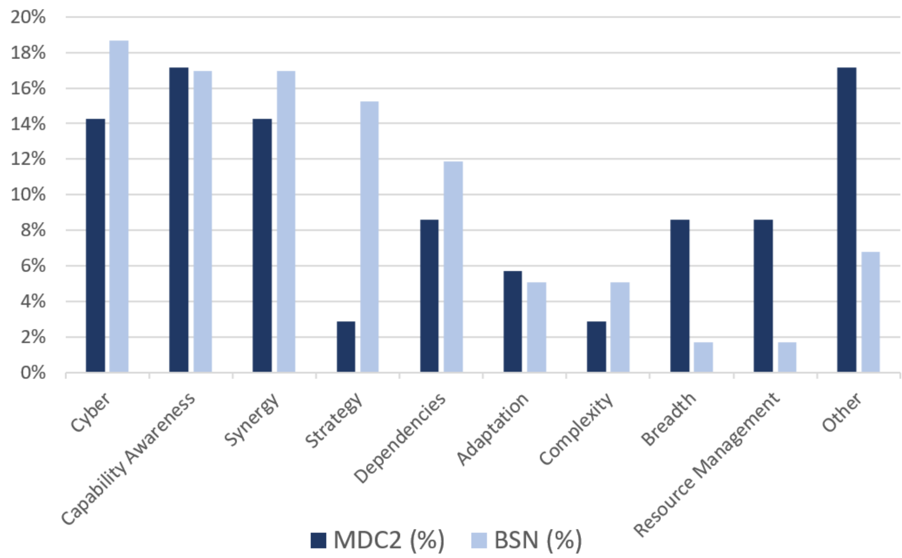

Figure 5: *Responses by Game Version to [PostQ22] "What did you Learn?" Bars show percentage of the total number of positive comments received.*

Participants explicitly mentioned an increase in cyber domain knowledge. This is believed to be connected to elevated focus on integrating cyber operations. Participants increased their knowledge of military capabilities (capability awareness) and how they can work together in the battlespace to achieve effects (synergy). The number of responses related to strategy reveal that the changes made to BSN increased the number of participants who reported learning MDO strategy. Learning about military dependencies was also mentioned in the top five categories, which is most likely due to the requirement mechanic inherent to the game. Requirements are listed on the cards identifying the support and logistics prerequisites required to employ that specific card.

Instructor responses further emphasize that the game is well-suited to teach MDO. These experts were asked "What did your students learn while playing the game?" One noted capability awareness, dependencies, and strategy. Specifically, they wrote, "Students [learned] about asset capabilities and dependencies within multi-dimensional operations. Students were exploring strategic and operational planning and execution using the assets." Another commented that the game taught breadth: "They learned to look beyond their focused learning and to understand there are many different aspects to our chosen profession. National defense is wide spectrum of different operations that provide offensive and defensive effects. It helped them begin to understand that not every problem has a kinetic answer." A third commented on the cyber and non-kinetic elements and dependencies, writing, "[The game] provided an understanding of how IO and Cyber would fit into conventional warfare. Helped them understand dependencies and limitations in warfare." The students and educators observing the experiments identified some of the very same learning outcomes that point to the effectiveness of the game to teach key MDO concepts.

5.3 [RQ3] What Effect Does This Particular Game Have on Players?

A large majority of players reported the game had a positive effect and created a fun and engaging classroom experience. Participants responded to these statements on a 5-point Likert scale:

[PostQ3] I enjoyed the game.
[PostQ4] I was focused during the game.
[PostQ26] This game helps players see the importance of MDO.
[PostQ8] The game helped me better understand MDO.
[PostQ9] The game offered valuable education and training.
[PostQ29] I would recommend this game to others.

The comparison of the major game versions show a similar result in both enjoyment and focus, with focus scoring the highest of any of the game response factors. 90% responding "Agree" or "Strongly Agree" with PostQ4. Increased player engagement is strongly linked to learning in other serious game studies, [11] for example. Of the remaining eight participants, six responded "Neither Agree Nor Disagree" to the same statement. All of these were from the 13O and ACSC experiments who may have been distracted by other academic priorities. Therefore, we hypothesize that, while the game elicits high engagement, environments linking game performance to course grades or other performance measures will increase engagement. Although, this may also increase frustration and decrease overall enjoyment for losing players. Figure 6 shows BSN performed consistently higher in four categories summarizing game quality and delivery of LOs. This reveals that engineering efforts successfully improved the game making it seem more valuable to students, helping them realize the importance of MDO, and improving their understanding.

The game elicited strong emotional responses from a majority of players, which was evident through direct observations. Many participants cheered, pumped their fist, or banged on the table during the in-class sessions in response to game events. Abdul Jabbar and Felicia [43] show that both emotions and cognition are central in learning and engagement in

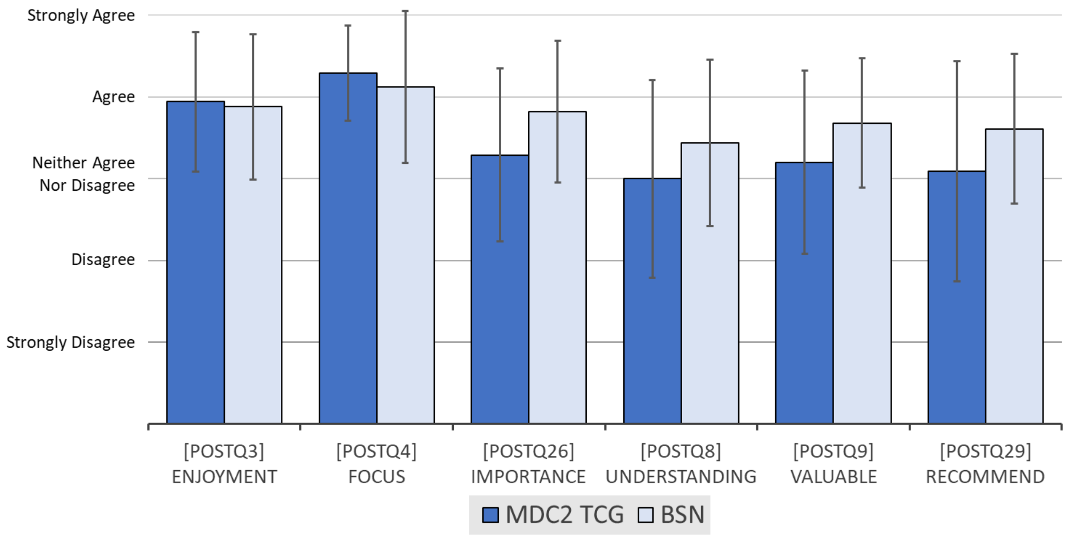

Figure 6: *Game Version Comparison (N=83). Error bars show* ± 1 *SD.*

game interaction. 48 participants were asked, "What emotions did you feel while playing the game?" This question was added after experiment 3 and was answered by 41 participants. Many participants listed more than one emotion leading to 69 separate responses. Frustration (15), confusion (12), excitement (12), and enjoyment (8) were the highest reported emotions and it was common for participants to list both frustration and confusion (5 times). One participant responded, "Frustration, joy (when winning)" which describes the trend that positive game outcomes (winning) led to positive emotions (enjoyment and excitement) while losing led to more negative emotions (anger and disappointment). Although frustration seems like a negative emotion, this was considered a positive result by the researchers since frustration can be a catalyst for learning. Realizing a knowledge or experience gap is the first step to conscience learning. One participant said he or she felt "frustrated (but that was a good thing!)." The positive side of frustration is that players are learning what does not work, challenging their preconceptions about MDO. Defeat is a good teacher. Confusion, on the other hand, was not positive as it points to a lack of understanding of the game. This was not correlated to time spent reviewing game materials, but is likely due to the game's complexity.

The quantitative data shows the game performed well in the classroom increasing military readiness in key areas of MDO. In the pre-survey, participants were asked to rate their current degree of readiness in these areas using the 5-point scale shown on the left side of Figure 7:

[PreQ26] Identification of military capabilities and their general role/function.
[PreQ27] Military strategy development.
[PreQ28] Linking cyber threats to corresponding defensive capabilities.
[PreQ29] Applying Multi-Domain thinking in your operational context.
[PreQ30] Anticipating enemy actions.
[PreQ31] Adapting to operational environment and enemy strategy.
[PreQ32] Continuing to execute a mission through uncertainty.

In the post-survey participants were asked how much the game improved their readiness based on the 4-point scale in Figure 7. Responses were gathered and summarized in custom matrices, as shown in Figure 7, which is color-coded to highlight the desirability of each of each cell to educators.

The colors describe the areas of the matrix that correspond to neutral, positive, and excellent results. The matrix and the three result categories are unique to this study and created to reveal the game's strengths and weaknesses. Providing a 5-point scale on the degree of

Linking Cyber Threats to Defensive Capabilities (N=83)					
		Degree of Improvement			
		Not at All Improved	A Little Improved	Much Improved	Very Much Improved
Prior Level of Readiness	Not at all Ready	5	8	6	1
	Slightly Ready	4	20	12	3
	Moderately Ready	4	9	5	1
	Very Ready	3	0	1	0
	Extremely Ready	0	1	0	0
Totals		**Neutral (orange): 24 | Positive (green): 52 | Excellent (blue): 7**			

Figure 7: *Matrix Depicting Prior Readiness and Growth Due to Game Play*

improvement would improve the matrix in future experiments. Negative responses were not possible as it was assumed that participants could not regress in their military readiness. The orange area marks the responses that are not desired because they show no growth in learning or only a little improvement for those with no prior experience. The green area marks a positive result showing those participants who were much improved and began the experiment at or below a moderate level of readiness. It also includes those who showed little improvement but reported some prior readiness. The excellent results are marked in blue highlighting those with significant prior training who still improved or those with any prior level of readiness who reported noticeable improvement.

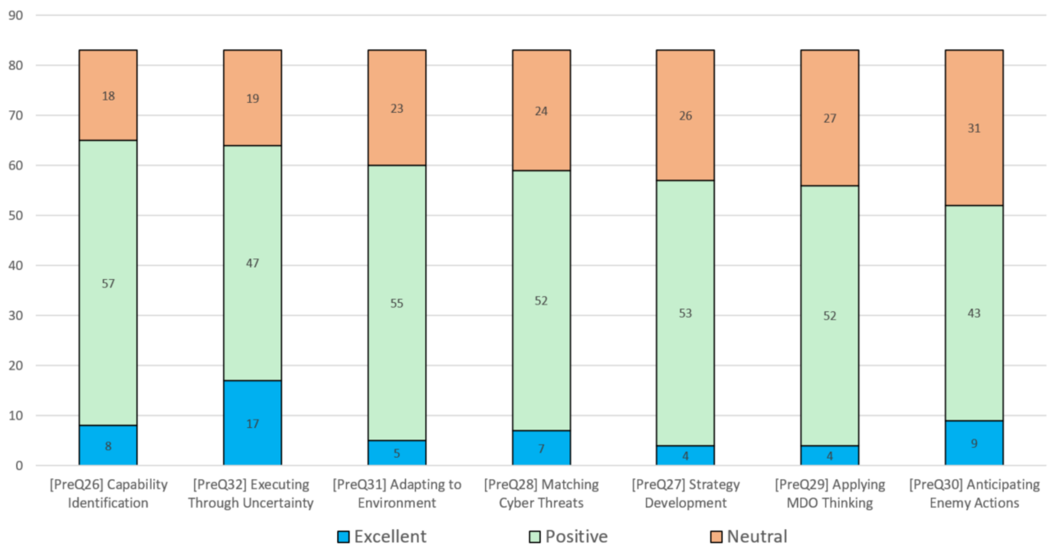

Figure 8: *Game Effects on Individual Readiness (N=83)*

The results from all seven area are graphed in Figure 8. The graph shows the games' ability to improve military readiness in 62% to 78% of participants. The neutral results may be explained by the nature of self-reported learning. One empirical study measuring the effect of active teaching methods found while students who received a lecture using active methods scored better on tests, they self-reported lower levels of learning than students who passively observed a lecture [44]. A serious game is similar to the active teaching described as it forces students to grapple with the content on their own, while potentially disguising the effort as an enjoyable experience. If this same effect occurs with the game, students may actually achieve a higher level of learning than they report because of the effort required to play the game versus sit through an organized lecture. The neutral results may also be explained by a lack of definition of what is valuable MDO knowledge. As discussed, the concept of MDO is still nebulous and ill-defined, meaning that the players themselves probably cannot accurately identify what is beneficial MDO learning. The results may also be explained by too little time to play. For example, if students do not understand the game, they would find it difficult to grow in their ability to anticipate enemy actions. Finally, poor game design and implementation may have hampered learning. Specifically, game complexity was often identified as a barrier to learning and playing the game. This emphasizes the need to develop instances of the Intro Game level of the framework for first time players.

5.4 [RQ4] How Time-Efficient is Course Integration?

Instructors may desire to use tools like serious games to increase their courses' engagement, however the cost to create a product or modify an existing one may be prohibitive. Questions in the instructor survey, which was distributed to the five eligible instructors who observed their students during the experiment, addressed this concern. Three of the five course instructors completed surveys about their perception of the game and its integration into their course.[24] All reported at least two hours of game interaction. All agreed that the game supported their LOs, fit well into their course, and they would recommend the game to other instructors. Additionally, all disagreed that the game was too complicated for the subject matter, validating that the game's complexity was appropriate. The instructors also completed open responses on integration time. Without researcher facilitation, the effort required for integration ranged from 8 to 20 hours. In contrast, the time to create their own similar tool would require several months to two years. This reveals the value of education and training tools that are mature and readily available to instructors to enhance the engagement value of their courses.

5.5 [RQ5] Does the Game Framework Facilitate MDO Innovation?

Due to the difficulty of measuring the game's ability to produce innovation and the ambiguity of defining quality MDO innovation, no specific post-survey questions referred to innovation. However, open responses point to several outcomes linked to innovation. First, strategy was mentioned as a learning outcome 10 times and 20 participants reported that they enjoyed the strategy aspects of the game. Additionally, 15% of those questioned reported that strategy development was the game element that contributed most to their learning, and 17% said this element was the most fun. Strategy is linked to innovation because players must develop better solutions to improve game outcomes and choose the most beneficial paths within the game environment. There is no predestined path to victory and players' success and failure are determined by numerous factors. The innovation aspects are further enhanced by the game's ability to lower the consequences of failure making strategy changes easy and (potentially) rewarding. Second, participants identified fourteen distinct areas in response to the question, "What did you learn from playing the game?" This points to the value of the game as a tool for innovation because it does not limit players to a defined set of learning outcomes. By putting the student in the driver's seat and providing a dynamic setting for experimentation,

[24] Five instructors participated in the experiment as observers while their students completed the experiments. Written feedback via email was received from the two remaining instructors. All other instructors were not eligible to complete questionnaires because they did not observe experiments or were part of the research team

BSN creates an environment ripe for innovation. In addition, the repetitive nature of the game may help shape future MDO strategies by allowing strategy developers to quickly test new and unique strategies. This will be further improved by adding more capabilities and increasing the realism of attack and defense actions. These development efforts and the collection of data needed to analyze the merits of player strategies would be best served by a digital version of the game.

6 Discussion and Implications

This study has implications for current and future MDO education and training as well as serious game design and implementation.

6.1 Adaptation is Central to Future MDO Success

Participants noted MDO concepts that they learned through playing BSN that are consistent with the current discussion. These include capability awareness and synergy. However, adaptation, strategy, and dependencies were also identified as central to learning. Adaptation, for example, needs to be a central concept in future MDO definitions and discussions. It is closely linked to the anticipation of enemy actions and ability to execute a mission through uncertainty. Future MDO conflicts will require operators and strategist who can quickly orient to their environment and create the needed effects with available resources. In a contested environment, where capability availability will be severely limited, the most adaptable warfighters will likely have the best chance of success.

6.2 Appropriate MDO Educational Materials are Needed

Experimentation reveals that the concept of MDO requires further refinement aided by appropriate educational materials. These materials must allow for exploration and innovation while teaching domain fundamentals. Many players, even those with above average operational experience, wanted cyber capabilities to trump kinetic capabilities during conflict. This highlights misconceptions about non-kinetic capabilities. While advances in cyber warfare capabilities may produce more potent effects in future conflicts, current capabilities cannot thwart enemy kinetic attacks. In the game framework, cyber capabilities were limited to hinder and confuse enemy actions without inflicting physical damage to enemy assets. These comments reveal that some students may think too much about what is fun and entertaining instead of what is currently possible. Additionally, one participant in the ACSC experiment wrote that he or she learned, "Improper relationships for multi-domain interaction. This game didn't show the integrated nature (requirement) for successful MDO." This reveals another gap in MDO education. To be successful in multi-domain warfare does not require the use of all domains, but the consideration of all domains in decision making. This reflects Goldfein's description of MDO as the blending of capabilities from one domain or many. If forces in one domain can effectively accomplish the mission, then a more complicated (integrated) approach may not be necessary.

6.3 Balance Required in Game Development

Play testing revealed the difficulty of balancing realism with simplicity and play-ability in serious games. Careful development and testing are needed to create an effective game that conveys and supports the correct LOs. Specific LOs must be defined and central in design decisions. While bad decisions can be made in the development process, intentional debriefing can help mitigate negative effects and correct misconceptions. Additionally, educators must be realistic about which and how many LOs to implement in a serous game. Continued focus on the LOs was necessary so that BSN was not overburdened by divergent requirements. Each learning objective proposed had the potential to detract from the current objectives and dilute the game's effectiveness.

6.4 Implications for Future MDO Education and Training

Two implications emerged for future MDO learning. First, serious games should complement the use of wargames to both explore and educate. Wargames are needed to closely simulate operations and inform current operators and strategic planning. However, other education and training will greatly benefit from serious games that use abstraction to save both money and time. Second, more cross-function emphasis is needed at all levels to encourage an *MDO-mindset* that considers how other domains interact with one's own functional community. During game debriefings, some participants were narrowly focused on their own functional area, which will create roadblocks as the military shifts to JADC2.

7 Conclusion and Future Work

Future research would benefit from a large study in an established military course where multiple classrooms can be dedicated to an experiment that controls game exposure time. This experiment should using a control group allowing direct comparison to those who receive no intervention as well as other forms of instruction such as lectures and interactive discussion on MDO. To measure the results, a standardized and independent evaluation tool is needed to evaluate MDO knowledge and higher levels of learning targeted by serious games. This experiment will be further improved by implementing a digital version of the game increasing accessibility and data collection opportunities. Digitization will improve play-ability and reduce the learning curve by automating rules and game management. It will also increase accessibility to military members who are disconnected from traditional classrooms. Additionally, it will allow the game to integrate into more classrooms leading to increased opportunities for data collection. In-game data collection would increase the volume and specificity of data. Data analytics, in turn, could establish the game as viable assessment tool to identify individuals with MDO talent both inside and outside the military. A digital game is essential to the Meta Game (Level 3) of the framework as it allows for inexpensive card additions and distribution, including opposing force capabilities. Digitization is a useful stepping stone to future AI research. This line of effort should focus on probabilistic model checking to validate game balance and building smart opponents that can "think" like near-peer adversaries. One possible AI method is the Monte Carlo search tree implemented for *Hearthstone* [28]. This next step will help to validate BSN as an MDO model, create relevant learning opportunities, and reveal the most promising game strategies for deeper analysis regarding real-world strategies.

MDO is a new, and to date ill-defined, concept created to take advantage of the growing complexity that defines the modern battlespace. This work attempts to explore this complexity through education and discussion of capability integration across warfighting domains using innovative education and training tools. It is an important step to better understand MDO, along with serious games, and their integration into current curriculum. Although a small minority of military members will not prefer games or find them engaging, overall they have great potential to improve student engagement and learning. The proposed game framework, and its current implementation, BSN, is poised to fill a current gap in MDO education between lectures and costly wargames. The empirical results confirm the game is both engaging and beneficial for MDO learning and can be integrated at a relatively low cost. Brigadier General Chad Raduege, a senior cyber leader in the USAF, responded positively to the game stating, "In our Air Force, we need various tools and methods to educate personnel who have a variety of experience and interests [45]." Engaging a broad population creates the opportunity to start and refine a conversation essential to transforming the way individuals view the world and respond in an increasingly complex and contested environment.

Disclaimer: The views expressed are those of the authors and do not necessarily reflect the official policy or position of the Air Force, the Department of Defense, or the U.S. Government.

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