GUIDELINES FOR A SYSTEM THAT BUILDS MOTIVATION IN SPACE OPERATOR RENDEZVOUS AND PROXIMITY OPERATIONS TRAINING

THESIS

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AFIT-ENV-MS-21-M-215

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT-ENV-MS-21-M-215

AN ANALYSIS OF THE EFFICACY OF THE LCOM IN ESTIMATING MAINTENANCE MANPOWER PRODUCTIVE CAPACITY

THESIS

Presented to the Faculty

Department of Aeronautics and Astronautics

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Engineering

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March 2021

AFIT-ENV-MS-21-M-215

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AFIT-ENV-MS-21-M-215

Abstract

Services provided by spacecraft, including communications and global positioning, are integral to small businesses, multinational corporations, and the United States Department of Defense. United States rivals recognize the need to undermine the military advantage provided by the space domain and are exploring ways to degrade these services in their warfare doctrine. In response, the United States will need space systems suited to counter these threats and personnel who are trained to respond to the new reality of a contested space environment. Training provides personnel the knowledge, skills, and abilities to operate, maintain, and support system operation within an environmental context. Research has shown that trainee characteristics can have a significant impact on training outcomes. An important characteristic associated with training outcomes is motivation. Motivation impacts how often and intently a person engages in any activity. Students lacking motivation do not engage in thought related to the training content and thus are unable to learn. An approach to improving motivation in the classroom is gamification. Gamification brings entertainment into the education practice to motivate students to learn. Gamification is not a "one size fits all" solution to improving motivation, so proper implementation is needed for success. This paper characterizes the knowledge, skills, and abilities needed for operators to engage in rendezvous and proximity operations. This paper also reviews the academic literature and written guidelines for developing motivation in an interactive environment for improving space operator training. A gamified system should include a rapid feedback process and provide the opportunity for students to practice the knowledge, skills, and abilities they are

learning without consequence. Students need to be taught how to maneuver in space, basics of the space environment, constraints for spacecraft, and factors that impact maneuvering decisions. A gamified system should motivate students using self-determination theory, the core motivators, and by understanding the individual characteristics of trainees.

Acknowledgments

I would like to give thanks to Dr. Michael Miller for all the aid and insight he provided to me in choosing and completing this thesis. I would also like to thank Captain Justin Oryschak for the joint interviews he allowed me to be a part of and the insight he provided on space operations. I would like to extend the same thanks to Dr. Richard Cobb for giving me the opportunity to work on this topic and for providing the chance to join him in learning about space operator tools being worked on which aided in the development of this research.

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I. Introduction

General Issue

To deter adversarial actions and support diplomatic activities, the Department of Defense (DoD) needs to provide combat-credible military power. Previously the United States could deploy, assemble, and operate their forces in space as desired. The advantage in space once held by the U.S. military has begun to wane. The U.S. is now engaged in inter-state strategic opposition which includes nation states that deploy predatory economics, those willing to invade surrounding nations, and others who seek veto power over the economic, diplomatic, and security decisions of its neighbors. Finally, smaller nations are seeking to employ technology advances to increase their influence by disrupting worldwide stability. With the loss of economic and technology supremacy, which has enabled military superiority, the U.S. is now challenged in all operating domains as adversaries disrupt principles of sovereignty, exploit ambiguity, and intentionally blur the lines between civil and military goals (Mattis, 2018).

Ensuring common domains remain open and free is a key objective of the U.S. DoD (Mattis, 2018). One of the key domains the U.S. has sought to keep free is space. Space is integral to small businesses, multinational corporations, and the DoD alike. Space-based capabilities enable commerce by providing worldwide communications, logistics support through global positioning and tracking, and monitoring of space-based threats to earth-based communication and electronic dissemination. All of which are essential to the global economy. Simultaneously, space provides the U.S. DoD a medium for global information collection, worldwide communications, the ability to guide and position military forces and weapons to their targets, and the ability to perform command and control of forces in multiple theaters simultaneously. These capabilities provide military commanders intelligence, surveillance, and reconnaissance allowing them to understand the security environment (Department of Defense, 2019).

Russia and China recognize a need to undermine the military advantage the space domain offers to the U.S. and are contemplating and exploring ways to degrade space-based missions in their future warfare doctrine. Both countries are pursuing an array of anti-satellite weapons to fulfill this objective. These weapons may include destructive systems, directed energy weapons, and on-orbit satellite activities such as rendezvous and proximity operations. There is also a growing threat of electronic warfare against space assets. These threats will likely include jamming and dazzling capabilities against military satellites. The future of space warfare will likely include a blend of electronic warfare and cyber capabilities which seek to deny and degrade information networks (Department of Defense, 2018).

Problem Statement

The existing U.S. space architecture was not created with the emerging threats in mind. Safety of space assets was assumed to come in the form of the technical challenge associated with targeting or disrupting them. The astronomical cost of each system also made redundancy hard to justify when combined with the assumed low risk of threat. This combination has resulted in an expensive and fragile U.S. space architecture upon which the military relies, now vulnerable to exploitation by adversarial forces. Space, much the like air, sea, and electromagnetic domains, is where the U.S. will have to fight for the ability to access and exploit the domain rather than assume it is safe and unchallenged (Colby, 2016).

The United States Space Force formation creates a force with the goal of seeking to regain secure access to and freedom to operate in space (McCall, 2019). This starts with the DoD producing new satellites that are more maneuverable and resistant to jamming. Each would aid in the survivability of space systems. Next, new radar systems are needed to enhance the current level of space situation awareness and enable the U.S. to better anticipate and understand threats in space (Colby, 2016). Then the number and quality of space-rated personnel needs to be increased. The personnel will need to include engineers, scientist, intelligence experts, operators, strategist and more (Department of Defense, 2018). All the personnel will need to be trained to handle the new reality of a contested space environment, including having a thorough understanding of rendezvous and proximity operations (RPO) in which satellites are maneuvered near other satellites. Students need to be motivated to learn and tackle new problems presented by adversaries as they arise. This will require students to become self-learners dedicated to continually learning about the threats space assets encounter and how to counter them, which may be non-intuitive in the different orbital regimes.

Research Hypotheses

This thesis hypothesizes that rigorous requirements gathering, research, and modeling will lead to a system capable of motivating students to learn about space operations. It is hypothesized that by interviewing members of the space community, an understanding of what is required to perform the duties of a space operator can be obtained and documented. It is further believed that by researching human motivation within interactive environments, a framework of requirements can be developed to encompass what is needed to encourage motivated self-learning in a training environment. Finally, it is hypothesized that modeling the findings will aid in conveying the ideas of the research performed.

Research Questions

- What must space operators know to fulfill their role and be successful in RPO?
- How can space operators be motivated to learn in a training course and beyond?
- What are the factors that would alter the method of motivating space operators to learn and how could these methods be integrated into an interactive training environment?
- What are the requirements for an interactive training environment to support RPO education within space operator training?
- What are the important attributes of the training and organizational environment which motivate continued learning?

Methodology

The method that will be used to develop requirements for a system to improve student motivation during space operator training will begin with collecting space domain knowledge. Space domain knowledge will come from doctrine and documentation for current operations. The initial knowledge will be used to develop a concept map that will serve to consolidate and organize the information. Interviews with space professionals will then take place utilizing the critical decision method. The information obtained from the interviews will then be used to update the concept map. A functional abstraction hierarchy will then be developed to highlight the goals and functions of space operator training. A goal decomposition will be used to divide the work of the space domain up and highlight what satellite operators need to do. Visualizations will then be developed to document and convey important aspects of the space domain.

The process of gathering domain knowledge about motivation will then begin. The knowledge obtained will be consolidated into a second concept map. A causal loop diagram will be developed to better understand the motivation domain. The combined information from the space and motivation domain will then be used to generate requirements for an interactive environment to support RPO training.

Research Tasks

The following tasks will need to be completed to accomplish the proposed method.

- Review literature on the tasks and concerns of space operators.
- Interview experts to learn about their experiences and recommendations for what new students should know to be successful as satellite operators.
- Consolidate the acquired knowledge of the space domain into a concept map.

- Develop a functional abstraction hierarchy to model the high-level goals and functions of the space operator work domain.
- Develop a goal decomposition to assign roles to the functions of the space operator work domain and identify which functions need to be taught to satellite operators.
- Review literature on the motivation domain.
- Consolidate the acquired knowledge of the motivation domain into a concept map.
- Generate a causal loop diagram of the motivation components.
- Model a lesson plan by combining the space operator task requirements and the motivation components.
- Model the flow of a course utilizing the motivation components.

Assumptions/Limitations

The following assumptions are made in the current research.

- Not all students sent to space operator training are highly motivated to learn and excel.
- Enough information can be obtained about the motivation domain through a literature review to be sufficient in guiding system requirements generation.
- The information that goes into each lesson topic does not need to be defined in this thesis since there are other avenues of obtaining the needed information.

- The space professionals and existing documentation will provide enough information to adequately understand what operators need to know to perform their duties.
- The effectiveness of the proposed lesson plan will need to be evaluated after it has been utilized. The evaluation will need to be done over a length of time that is infeasible for this thesis.
- A system model that helps readers understand the ideas proposed will be created. This model will not be a representative user interface or involve code.
- The system to be specified is assumed to be either a single-player or competitive two-player game.

Implications

This thesis will seek to combine the learnings from the cognitive field about motivation with the model-based systems engineering practice to suggest requirements for a RPO training environment. The knowledge gained or the process developed in this endeavor can be applied to other disciplines and institutions within the DoD, public education, and private sector. Teaching students to be life-long learners and grow as their time in the field grows can lead to improved overall performance from future workers.

Document Overview

Chapter 2 contains a literature review of the motivation domain and focuses on how motivation can be incorporated into the space operator training process. Chapter 3 describes the methodology used to develop the requirements for a system that will teach space operators and motivate them to learn in and out of the classroom. Chapter 4 contains the results of the methodology and covers what the key finding are. Chapter 5 concludes the paper by reviewing the findings of chapter 4 and suggesting future work that could be done to further this research and field of study.

II. Literature Review

Where training fits into the big picture

Handling day to day operations and adapting to novel situations begins with proper training. Training teaches personnel to deal with the complexities involved in demanding environments such as the control and protection of space assets (Grossman, Oglesby, & Salas, 2015). The three ways that individuals can learn new material are formal learning programs; individual, informal learning; and individual, intentional learning. Formal learning programs are structured learning opportunities organized by others. Individual, informal learning is information obtained while reacting to everyday life experiences. Individual, intentional learning is the process of finding a subject that one wishes to learn about and seeking ways to learn about it (Fink, 2003). Training is an important aspect of human system integration (HSI) needed to implement an effective system. Before training begins, an analysis of what trainees need to know, often referred to as the job or task analysis, must be conducted. The analysis uncovers the learning objectives for the training, such as contextual factors surrounding the job and the knowledge, skills, and abilities (KSAs) required for effective performance (Grossman, Oglesby, & Salas, 2015).

An analysis of the people who need to be trained is also necessary to establish a baseline for the KSAs possessed by the individuals who are entering the training program. The personnel analysis can also assess trainee characteristics, which research has shown can contribute to much of the variance in the training outcomes. Cognitive ability, self-efficacy, goal orientation, and motivation are included among the characteristics which are known to influence training outcomes. Cognitive ability indicates the extent to which an individual will be able to understand complicated concepts, utilize various types of reasoning, adjust to different environments, and learn from their experiences. Self-efficacy is an individual's belief about their own ability to perform a given task. Goal orientation can vary from mastery to performance focused where someone with a mastery or learning orientation is more interested in obtaining new knowledge or skills and a person with a performance orientation is more focused on appearing to acquire training content for the sake of high marks or grades (Grossman, Oglesby, & Salas, 2015).

Fink mentions a concept like goal orientation referred to as a person's sense of self as a learner. He states a person's sense of self as a learner will also impact how they react to training. Some people fail to form a clear understanding of what they need or want to learn, which is attributed to a weak sense of self as a learner. Others are proactive about their training experience and actively seek to discover what it is they need to learn and why, which is attributed to a strong sense of self as a learner. The strong sense of self would be comparable to the mastery orientation and the weak sense of self would relate to the performance orientation. Fink goes further to say that to improve training one must help students learn something that is significant about the subject matter and help students develop a strong and proactive sense of self as a learner (Fink, 2003).

How motivation is involved

An issue found in training is that many students lack the motivation to learn (Alsawaier, 2018). Motivation refers to the level of desire to take an action (Eyal, 2019). The amount of training content a trainee learns is related to their motivation to learn (Grossman, Oglesby, & Salas, 2015). "Intrinsically motivated activities are those that the individual finds interesting and performs without any kind of conditioning, just by the mere pleasure of carrying them out" (Alsawaier, 2018). Internal and external factors can impact trainee motivation to learn and transfer that learning to the workplace. Internal factors such as perceived utility is high when trainees believe participating in the training will provide value to them. This value can be that the KSAs being taught are required to perform the job they find value in or enjoy, they feel a desire to improve their performance, and by improving performance there will be some level of return on investment (Grossman, Oglesby, & Salas, 2015) (Berkling & Thomas, 2013). External factors such as organizational climate, organizational commitment, supervisor support, peer support, and subordinate support generate high motivation when buy-in is established. Organizational climate was found to be the most important factor in a study focused primarily on motivation to transfer. Motivation to transfer refers to the trainee's intent to utilize the skills and knowledge obtained from the training environment in the real world (Seyler, Holton III, Bates, Burnett, & Carvalho, 1998).

A student can have different levels of motivation depending on the phase of training they are in. Before training their motivation can be influenced by reputation of the training which could come from peers or other members of the organization (Seyler, Holton III, Bates, Burnett, & Carvalho, 1998) (Grossman, Oglesby, & Salas, 2015). During training the features of the training can impact training effectiveness. During training, information about the KSAs should be presented, the proper use of the KSAs should be demonstrated, a chance to practice the KSAs should be allowed, and feedback on use of the KSAs should be given (Grossman, Oglesby, & Salas, 2015). After training, the transfer climate of the gaining organization will largely determine a trainee's motivation to transfer. “Transfer climate has been defined as situations in the organization, both observable and perceived, that hinder or facilitate the use of newly acquired KSAs on the job” (Grossman, Oglesby, & Salas, 2015).

Influencing the motivation level of an individual requires the manipulation of what Fogg calls the core motivators. Fogg states that the core motivators are to seek pleasure and avoid pain, seek hope and avoid fear, and seek social acceptance and avoid rejection (Fogg, 2009). Students that have high levels of motivation believe that they are capable of learning and that learning will lead to improved performance. This belief promotes continued effort throughout the training process (Grossman, Oglesby, & Salas, 2015).

Motivation in gamification

Motivation and engagement are central to the self-determination theory. This theory lists the three principles: autonomy, competence, and relatedness as being important to motivation and engagement. Competence is related to the motivation to persevere through difficulties and attain success. Autonomy relates to the need to make choices in pursuit of being responsible for one’s actions. Relatedness is about social status and connections with others based on mutual respect and interdependence. These three elements come together to fulfill the human psychological requirements to feel confident about their abilities, make choices, and compete or collaborate with others (Alsawaier, 2018).

A rising solution to the lack of motivation in the classroom is the use of gamification. Gamification is defined as “game-based mechanics, aesthetics, and game thinking to engage people, motivate action, promote learning, and solve problems”

(Kapp, 2013). The use of gamification can enhance motivation and engagement in students if it properly generates enjoyment (Alsawaier, 2018). To make a gamified training program successful it should adhere to the principles of self-determination and satisfy Fogg's core motivators (Fogg, 2009) (Alsawaier, 2018).

Implementing gamification

A test named the Bartle's Test of Game Psychology has determined that there are four types of gamers. Those that enjoy competing and playing against other players, called *killers*, are motivated by public recognition. Players who aim to achieve status with a high level of performance are called *achievers* and are motivated by tracking their achievement and progress. *Explorers* are players that enjoy collecting virtual goods and discovering new things. Explorers are more interested in pursuing quest and are not as interested in impressing others. Those who are good team players and collaborate with others in the game environment are called *socializers*. Socializers want to interact with others through mutual support. Understanding the various player types will help determine the factors that motivate them to play (Alsawaier, 2018).

To obey the self-determination theory competence principle, the gamified course should have a good feedback system, provide an appropriate challenge, provide sufficient build up for complex topics, have intuitive controls, variable rewards, and social engagement (Seaborn & Fels, 2015). In the classroom, teachers typically can only provide feedback to one student at a time and the process of grading work takes time. Games typically allow the player to make mistakes, allowing them to experiment which increases engagement through improving autonomy or self-determination. Games also can provide frequent and immediate feedback allowing players to experiment even more.

(Hanus & Fox, 2014) . If the challenge is too great, the course will generate disengagement causing students to lose interest and become worried and frustrated (Alsawaier, 2018). Hope can be created while building confidence in the trainee's abilities by following the competence principles (Fogg, 2009). Teachers typically present blocks of new information to the entire class in a way that grows in complexity, but it can be difficult to provide accommodations to individual students. Games can alter the difficulty and progression on an individual level which only allows a player to progress once they have mastered the required KSAs (Hanus & Fox, 2014). By making the game controls intuitive and easier to use, adoption and interest in the tool will increase. Unlocking perks and leveling up[1] satisfy a student's desire for competency by rewarding development and achievement (Eyal, 2019).

To adhere to autonomy the system should allow for customization from students in the way of profiles, avatars, a configurable interface, alternate activities, privacy settings, and notification controls (Seaborn & Fels, 2015). Providing autonomy helps maintain interest by keeping what psychologist term reactance, the instinctive response to threats on free choice, at bay (Eyal, 2019). Giving individuals rewards for things they would already do freely can cause the reward to be perceived as controlling and have a negative impact on intrinsic motivation. The same principle can cause students already interested in the class to lose interest if incentives to perform are needlessly added (Hanus & Fox, 2014).

[1] Perks in gaming can be thought of as niche abilities that can be unlocked such as a calculator which reduces their workload in future game play. Leveling up is an enhancement and sign of growth in gaming terms. Using the calculator example, the first level would be a basic calculator while the higher level might be a program such as MatLab to aid with doing calculations.

To provide a sense of relatedness the system should provide a way to compete or cooperate with others by forming groups, employing blogs, messaging options, and chat functions (Seaborn & Fels, 2015). By making it easier to share encouragement, exchange advice, and receive praise a system can satisfy the human need for social acceptance (Eyal, 2019). Social acceptance can be catered to through the relatedness elements and leaderboards (Alsawaier, 2018) (Fogg, 2009).

Generating extrinsic motivation with game elements is not enough to warrant the use of gamification, the objective should be to generate long term intrinsic motivation. This means that extrinsic motivators such as points, leaderboards, and badges, while helpful, will not be enough to produce a successful gamified course. Pleasure can be generated when students feel the game is fun to play. However, the implementation of gamification should not be a simple addition to the existing course architecture. Elements of the self-determination theory should be involved in the course design to help create the desired intrinsic motivation. In a traditional course, students earn grades based on how they perform tasks and demonstrate achievement. With gamification, it is important to reward the effort, not the winning or success of the venture. This means giving feedback to the students and allowing them to learn from their mistakes before allowing them to try again. This is not to undermine the importance of the task, but it is meant to motivate students to put in more effort while taking on different learning challenges (Alsawaier, 2018).

Measuring success

To determine the effectiveness of the gamified course, a method of measurement is needed. Various surveys can be administered to measure the intrinsic motivation, satisfaction with the course, effort put forth into the class, how useful participants feel the course will be in future work, how students feel their performance compares to the performance of their peers, and examinations to measure the material learned throughout the course. The surveys can utilize a Likert-like scale to assess responses to questions on an interval five to seven-point scale. A low number on such a scale represents disagreement and a higher number represents agreement with the statement. The examination can be multiple choice, fill in the blank, short answer, or any other form of examination that is deemed appropriate. Examples of the survey questions could be:

1. "I felt like I was doing what I wanted to do while I was working on the task" when trying to determine intrinsic motivation;
2. "In the last month, I have been happy taking this class" for class satisfaction survey. "In the last month, I feel I have put forth a lot of effort in this class" when trying to determine class effort survey;
3. "This course will help me achieve my future goals" when attempting to determine perceived utility; or
4. "In the last month, I have looked to others' performance to feel better about my performance" when trying to determine social comparison (Hanus & Fox, 2014).

Recommendations

Training in the space environment needs to develop the intrinsic motivation necessary to create lifetime learners in the domain (Fink, 2003). Gamification offers an avenue for achieving that objective if properly implemented (Seaborn & Fels, 2015). Key factors that will aid in the development of intrinsic motivation are the self-determination principles of building competence, relatedness, and autonomy in the training (Alsawaier, 2018). The use of Fogg's core motivators of seek pleasure and avoid pain, seek hope and avoid fear, and seek social acceptance and avoid rejection should also be considered in the course design (Fogg, 2009). To help determine what will influence Fogg's core motivators and the self-determination theory principles for individual students, an understanding of mastery and performance goal orientations as well as the killer, achiever, explorer, and socializer gamer personalities is necessary (Grossman, Oglesby, & Salas, 2015) (Alsawaier, 2018). Proper use of feedback frequency, individualized pacing, reward structures, competition, social structures, personalization, and control of how the training progresses will result in a course more likely to generate intrinsic motivation in students (Hanus & Fox, 2014) (Seaborn & Fels, 2015). Once elements of gamification, self-determination theory, and Fogg's core motivators have been incorporated into the course, an assessment of the impact should be performed to determine if the desired effects have been achieved or if adjustments are needed (Hanus & Fox, 2014) (Berkling & Thomas, 2013).

III. Methodology

Chapter Overview

The following lays out the method utilized to develop the requirements for a system to improve student motivation during space operator training. This method includes a multi-step process, which included the following steps.

- First space domain knowledge was collected from reviews of doctrine and existing operations descriptions.
- An initial concept map (CMAP) was then developed to depict the knowledge that space operators require.
- Interviews were then conducted with space professionals utilizing the critical decision method and the learnings from these interviews were used to update the concept map.
- This knowledge was then depicted in a functional abstraction hierarchy (FAH).
- A goal decomposition was then developed to assign roles to the goal of training space operators.
- The process of gathering domain knowledge to understand methods to support student motivation then began via another literature review.
- A CMAP was built covering the motivation domain.
- A causal loop diagram was developed to aid in the comprehension of the various facets of motivation.
- With the knowledge of the space and motivation domain, a lesson plan was assembled to describe the structure of the system requirements needed to foster motivation in space operator training. This lesson plan was depicted within a SysML block diagram. A SysML activity diagram was subsequently proposed to describe the behavior of the space operator class.

Components of each of these steps are described in greater detail within this chapter.

Concept Maps

A CMAP is a web-like model developed to capture concepts and the relationships between concepts relevant to a particular topic. The CMAP strings ideas together in a manner that allows a viewer to flow from each element of the domain and understand the interconnectedness of the concepts related to the topic (Crandall, Klein, & Hoffman, 2006). Although CMAPs are applied in many fields, in cognitive systems engineering, they are often used to help the researcher understand relationships and discuss these relationships with SMEs. The current research involved to creation of two separate concept maps. The first of these CMAPS was applied to the space domain. The idea of the literature review was to get a baseline understanding of the space domain before speaking with space professionals. The information gathered was then developed into a concept map (CMAP).

The CMAP development process started a question of how to teach space operators? The question was first answered using (documents reviewed) information available. The CMAP was then further developed by asking a similar question of subject matter experts. From this question stemmed the how and what of teaching space operators. Each node reads to the next node via the word or phrase connecting them, for example space operator training should teach orbital engagement maneuvers. The process of connecting words and phrases continued until the interviewee was satisfied or the information was exhausted.

An additional CMAP was developed to understand human motivation using gamified systems. The development of this CMAP began with a literature review pertaining to motivation in games and training as summarized in the previous chapter. The question used to create the CMAP was "what is involved in motivation in training?" From the question came the development of what impacts motivation and how the various faucets are related. The connections were made using the information available from the sources cited in the literature review. This CMAP did not involve interviews and instead focused on the knowledge available.

Interviews

Various interviews were conducted with individuals from the space operations domain. An interview with a Mission Design Engineer with the Space Test Program was conducted utilizing the critical decision method (CDM). The goal of the CDM was to have the interviewee recall an incident that was abnormal and required critical thinking to solve (Crandall, Klein, & Hoffman, 2006). The CDM began with the interviewee selecting an abnormal incident to discuss. The interviewee was then asked to discuss the highlights of the incident. Next the interviewer checked the timeline of the incident being discussed. Once the timeline was understood the interviewer asked questions to get a deeper understanding of the problem and the process the SME used to find a solution to the issue caused by the incident (Crandall, Klein, & Hoffman, 2006).

A separate interview with an instructor of the Air Force Advanced Space Operations School (AFASOS) to determine what the AFASOS sought to teach students and the learning objectives the instructor sought to achieve. The interview fed into the creation of an updated space domain CMAP, as well as requirements for the scope and objectives of the training system.

The other three interviews delved into the example user interface that was designed in Oryschak's thesis. Two of these individuals had experience in space operations squadrons. The final interviewee was an instructor in the AFIT orbital warfare research group that is involved in the development of a space game aimed at teaching space operators. These interviews focused on an evaluation of the interface developed by Oryshak (Oryschak, 2020) but provided additional insight into the thought processes and knowledge they apply to select orbital maneuvers during space operations.

Functional Abstraction Hierarchy

The functional abstraction hierarchy (FAH) in Figure 4 was developed to understand the higher-level and lower-level goals of the space operator training. Figure 4 was designed to better understand how the requirements fit together and satisfy the domain goals (Adams, et al., 2009). This representation includes a five-level hierarchy. The first level is referred to as the functional purpose. It represents the objective that the person or system is trying to achieve at a high-level. The following four levels include the abstract values, generalized function, physical function, and physical form. The abstract values level seeks to understand the above level by understanding the measuring criteria that would need to be fulfilled to accomplish the functional purpose. Next the generalized function related functions are identified. These functions define what needs to be done to fulfill the criteria of the above level. The physical function related processes define how the general functions are accomplished. The lowest level of abstraction is the physical form level which represents the actual objects or components needed to accomplish the physical functions or processes. For each level of the abstraction hierarchy, the level above any level being analyzed represents why the goal matters, the current level represents what the goal is, and the level below the current level represents the how the goal is accomplished (Adams, et al., 2009).

A goal decomposition as shown in Figure 5 was developed to assign roles to the goal of training space operators identified in the FAH. A goal decomposition is used to identify how the work should be divided to achieve the associated goal. By compartmentalizing the activities needed to accomplish a goal the training for each role can be reduced to only include the needed knowledge, skills, and abilities (Miller, McGuirl, Schneider, & Ford, 2020).

Causal Loop Diagram

After the space domain knowledge was organized the process of understanding the motivation domain started. Once the literature review was complete and the CMAP was put together a causal loop diagram (CLD) was made. The CLD was used to relate the various motivation concepts to one another and help make sense of the voluminous amount of data from the literature review. The CLD is a tool used to understand the influence and feedback structure of systems. The loops created help link ideas to one another by giving direction and polarity to the relationship. As one component rises another may rise or fall in response. The CLD brings all these loops together to aid in understanding the connectedness of the domain elements (Sterman, 2001).

Model-Based Systems Engineering

Once the knowledge building was complete for the space and motivation domains, the requirements derived from the two ventures was combined and represented using model-based systems engineering representations. This version of systems engineering converts the document-based practice to one that focuses on models to improve upon the systems engineering method. The system models are representations of concepts that could be created. The models used were an activity diagram and block definition diagram. The activity diagram models the behavior of the system. The block definition diagram models the structure of the system (Buede & Miller, 2016). Within this thesis the BDD is used to show the lesson topics that should be covered and what the requirements are to promote motivation while the activity diagram was used to depict how the motivation requirements fit into the course.

Chapter Summary

This chapter covered the methodology used to generate the requirements for a system to improve motivation during space operator training. A CMAP was created to consolidate the knowledge of the space domain. Interviews were conducted to further expand on the space domain CMAP. A FAH was then created to understand the goals of space operator training and how the requirements help satisfy those goals. The goal decomposition was created to separate the roles needed to train space operators and what goals each role has. Knowledge was then obtained in a literature review and consolidated into a CMAP of motivation in space operator training. A causal loop diagram was created to tie the various processes of motivation generation together. The resulting requirements for generating motivation in space operator training and space operator KSAs that need to be taught were combined into a lesson plan using a block definition diagram. The behavior of the space operator class was finally represented in an activity diagram. The next chapter describes the results of the methodology.

IV. Analysis and Results

Space Domain Knowledge

The development of space domain knowledge started with a literature review which fed into a baseline CMAP for space operator training. The initial CMAP included the gray items show in Figure 1. This CMAP was updated through interviews with a Mission Design Engineer involved with the Space Test Program. During this stage, the items highlighted in yellow, were added to the CMAP. Finally, additional interviews with representatives of the 533rd Training Squadron were used to update the CMAP as indicated in pink. As shown in Figure 1, operators should be taught items in three categories, including 1) how to maneuver in space, 2) basics of the space environment, and 3) the tools needed understand the space domain. These tools include items such as use of basic algebra to estimate maneuvers, graphs, plots, and other tools used to deduce information about objects in space. Students should also understand decision making in realistic situations. For example, decisions about maneuvers are made by a team and revolve around numerous variables such as fuel remaining, risk tolerance, and the satellite mission, as indicated on the right side of this diagram. Figure 3, which is a close up of the right side of Figure 1, also focuses on how information is obtained and the uncertain nature of that information over time. It was shown that classroom scenarios focus on the achievement of objectives, such as characterizing the opponent or reaching some location.

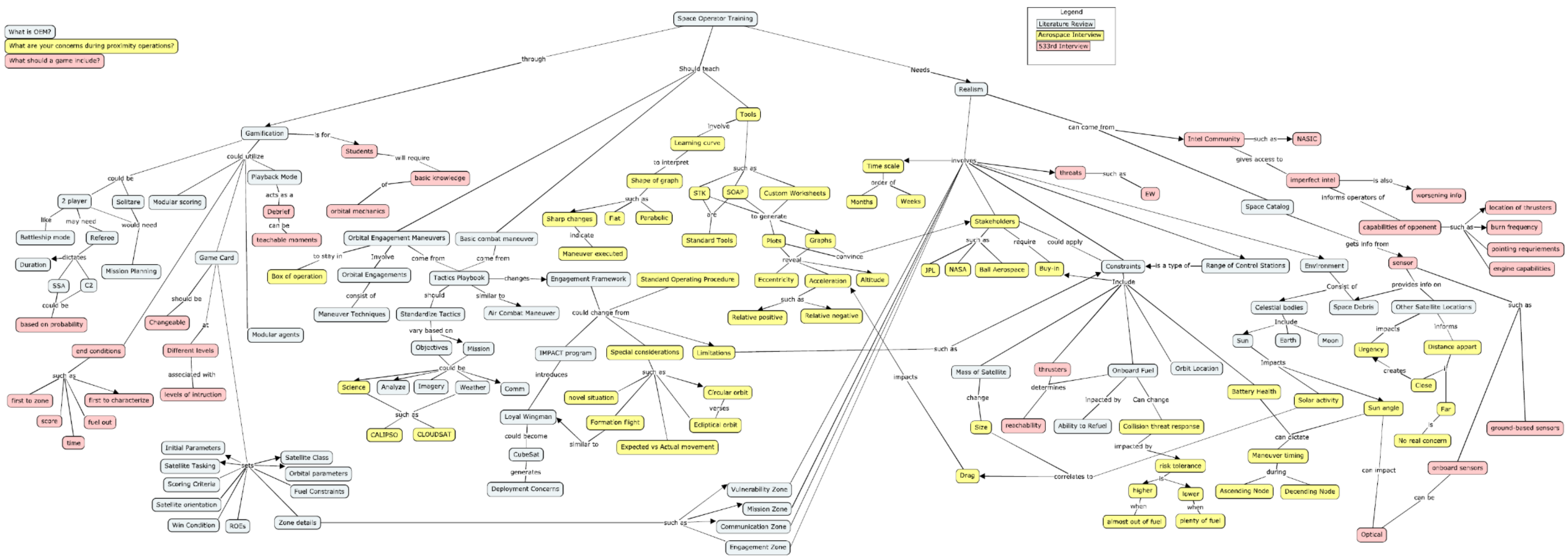

Figure 1 Space Domain Concept Map

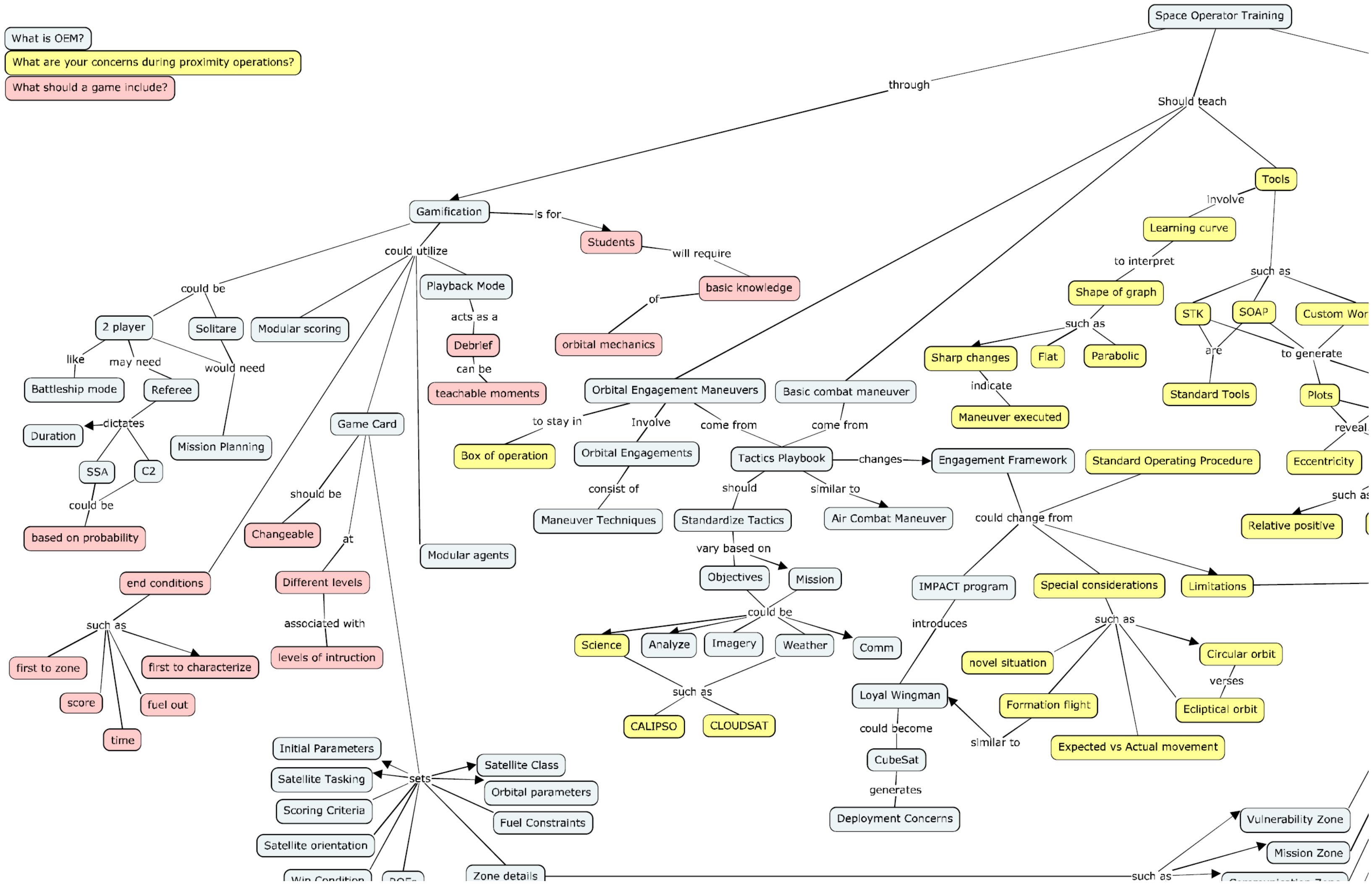

Figure 2 Space Domain Concept Map (left)

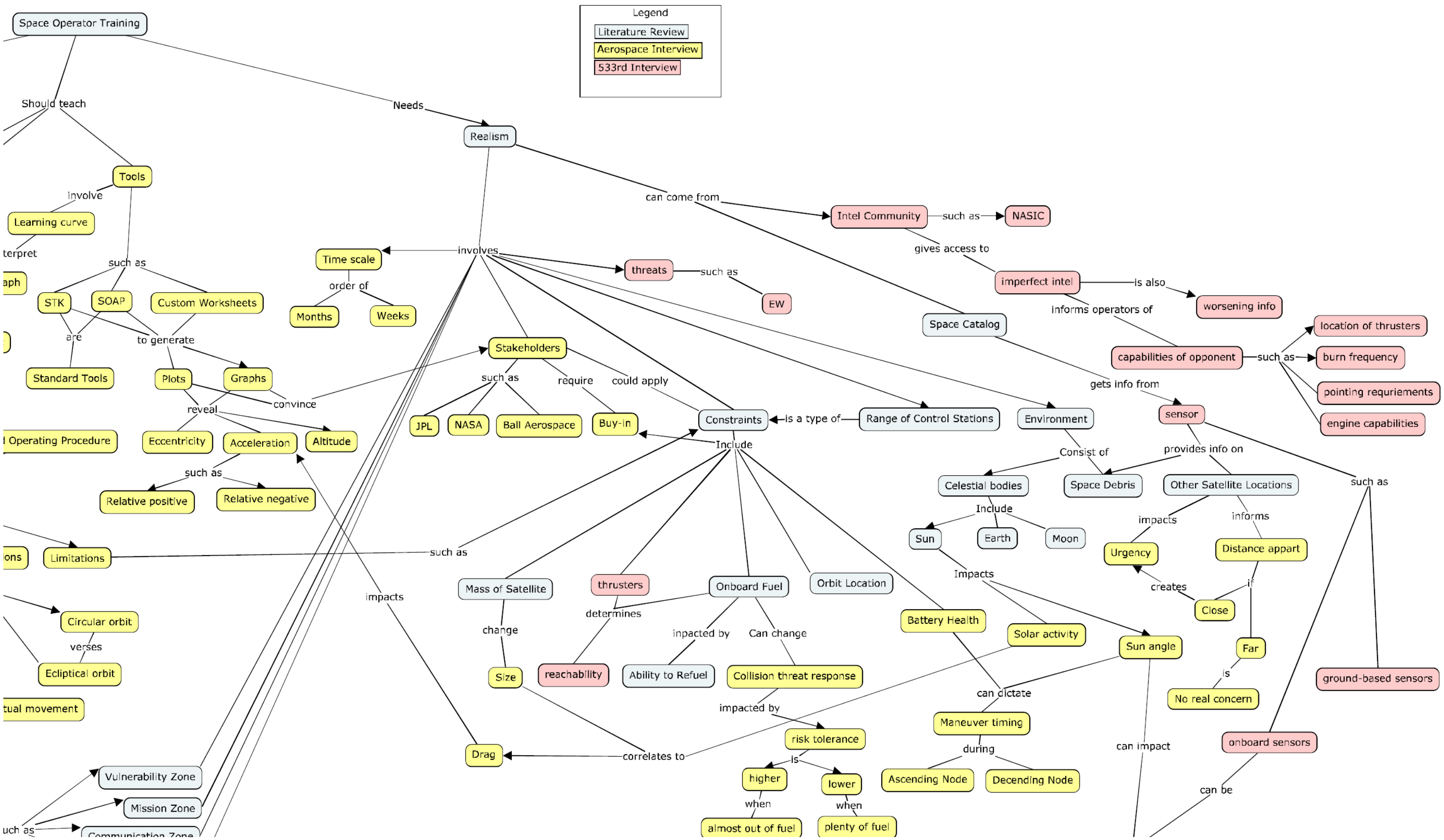

Figure 3 Space Domain Concept Map (right)

Also shown in Figure 2, which is a close up of the left side of Figure 1, are some concepts around gamification of this training. As shown, the game could be a single-player game with an artificial opponent or two-player battleship type game. Having modular agents play the role of intel analyst or mission manager directing students with information can help simulate working environments for satellite operators. Students playing the game will need to understand orbital mechanics and are expected to receive some education on the subject prior to playing. Feedback can be provided using a playback mode to highlight teachable moments. The game could utilize a scoring system or leaderboards to incentivize competition and motivate students with a competitive disposition. Scenarios can be generated on game cards to allow for adjustments to learning goals and difficulty.

After enough information about the domain was understood the goals of the domain were developed to better understand how the requirements fit together. This was accomplished using the FAH in Figure 4. Figure 4 highlights that the overall or functional objective of this thesis is to develop an understanding of the requirements of a system to train space operators and develop space operator tactics. The success of this can be judged by the ease of use presented by the system, the fidelity of the training, and training efficiency. Figure 4 shows that the generalized functions include training offensive tactics, training defensive tactics, and performing the satellite mission such as providing communications or optical intelligence of some location. Each of those functions can be achieved by understanding the position of the satellite being operated, understanding what is in the surrounding area, and by understanding the status of the satellite being operated. The position of the satellite will need to utilize a frame of reference to communicate the satellites position. Understanding the surrounding area would include information about other satellites and debris. Satellite status would require an understanding of constraints such as fuel remaining, thruster capabilities, communications windows, and battery health.

The goal decomposition shown in Figure 5 then separated the roles and helped identify that training satellite operators has different training goals from training mission managers or intel analyst. The top level of the hierarchy describes the top-level goal of training operators. The second level describes the subgoals that feed into achieving the goal of training space operators. For example, maneuvering and scanning for threats are important to the goal of training space operators. The layer below the subgoals show that some of the goals generate other goals that are not always performed by the same role. An example is that training offensive tactics which is performed by space instructors leads to exposing enemy vulnerability zones which is performed by satellite operators. The lowest level of Figure 5 shows the various roles that come into play for the fulfillment of training space operators. Satellite operators need to learn maneuvering, how to defend the satellite, and how to expose vulnerabilities of the opposition. Space instructors teach operators offensive and defensive tactic, provide feedback to operators, and aid in the simulation of the real-world environment. To properly teach operators, mission managers and intel analyst need to be represented in the training.

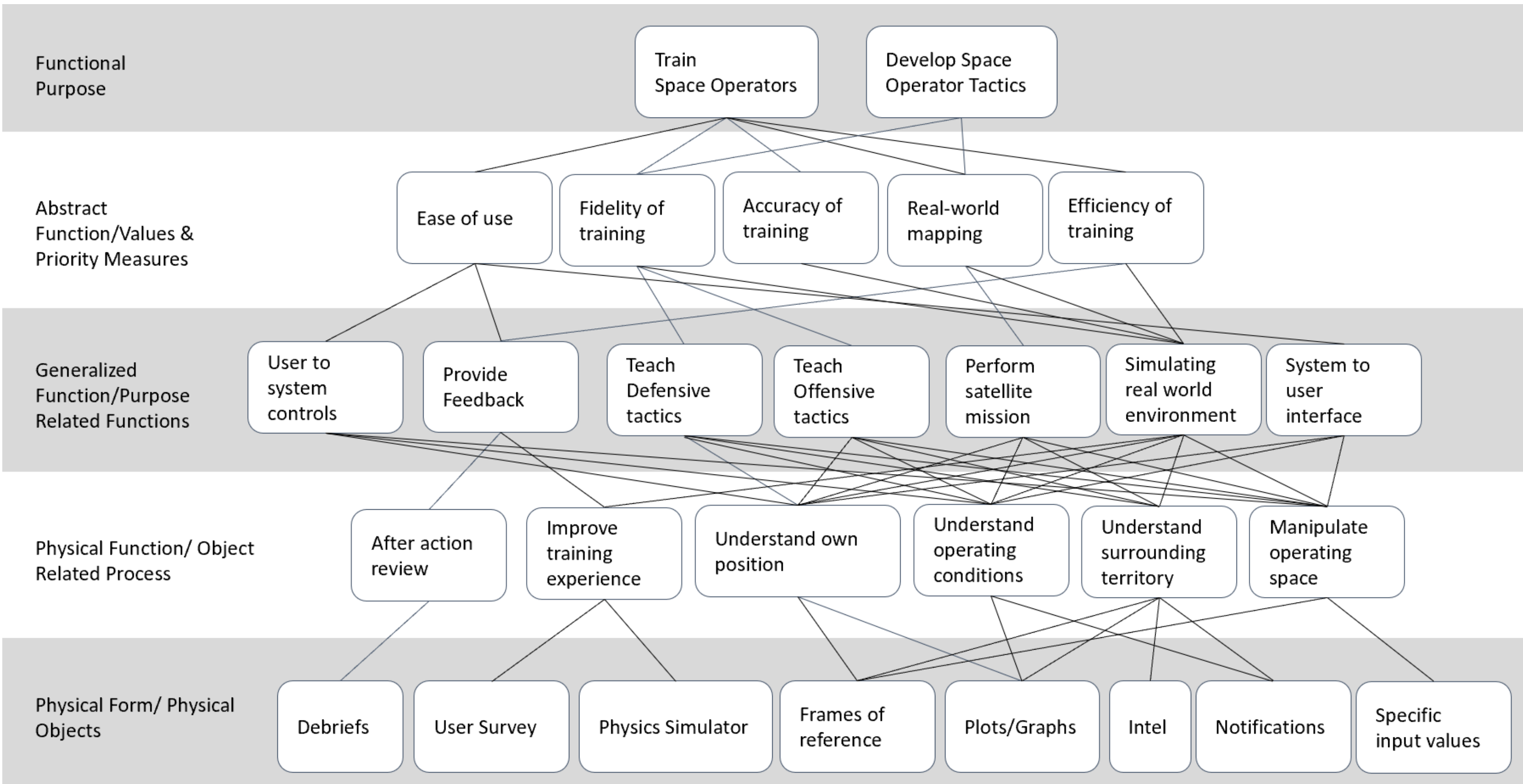

Figure 4 Functional Abstraction Hierarchy applied to space operator training

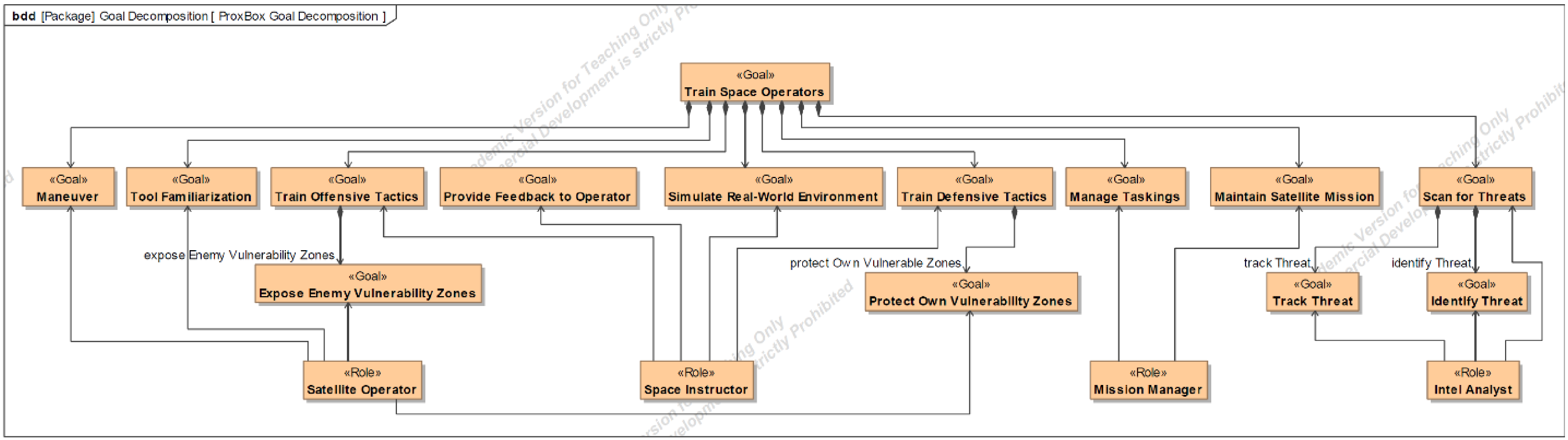

Figure 5 Goal Decomposition applied to space operator training

Motivation Domain Knowledge

The motivation knowledge building began with a literature review which can be found in the second chapter. After the review, a CMAP shown in Figure 1 was constructed to aid in understanding the information obtained. The CMAP shows that motivation is impacted by properly applying the core motivators, self-determination theory, and understanding trainee characteristics. Self-determination theory revealed that the level of difficulty should match the student ability which aids in building competence and the seek hope core motivator. Students should be given some level of autonomy via customization of their learning experience. Students should also be provided avenues to help, challenge, and congratulate each other to foster relatedness and adhere to the social acceptance core motivator. Gamification offers the ability to apply these motivators in an effective way. A gamified course can help students feel comfortable with the material by providing swift feedback and the opportunity to practice without fear of detrimental consequences a core motivator. Some students are motivated by competing with their peers and like to know how they compare. Other students want to be involved with their peers and are motivated by their ability to seek and provide aid as well as receive praise from their fellow students. Achievers are motivated by seeing their progress while explorers enjoy discovering all that the game has to offer by way of badges or extra information. Some of the tools that can motivate different trainee characteristics are leaderboards, trophies, chat functions, clear progress tracking, and clear goals.

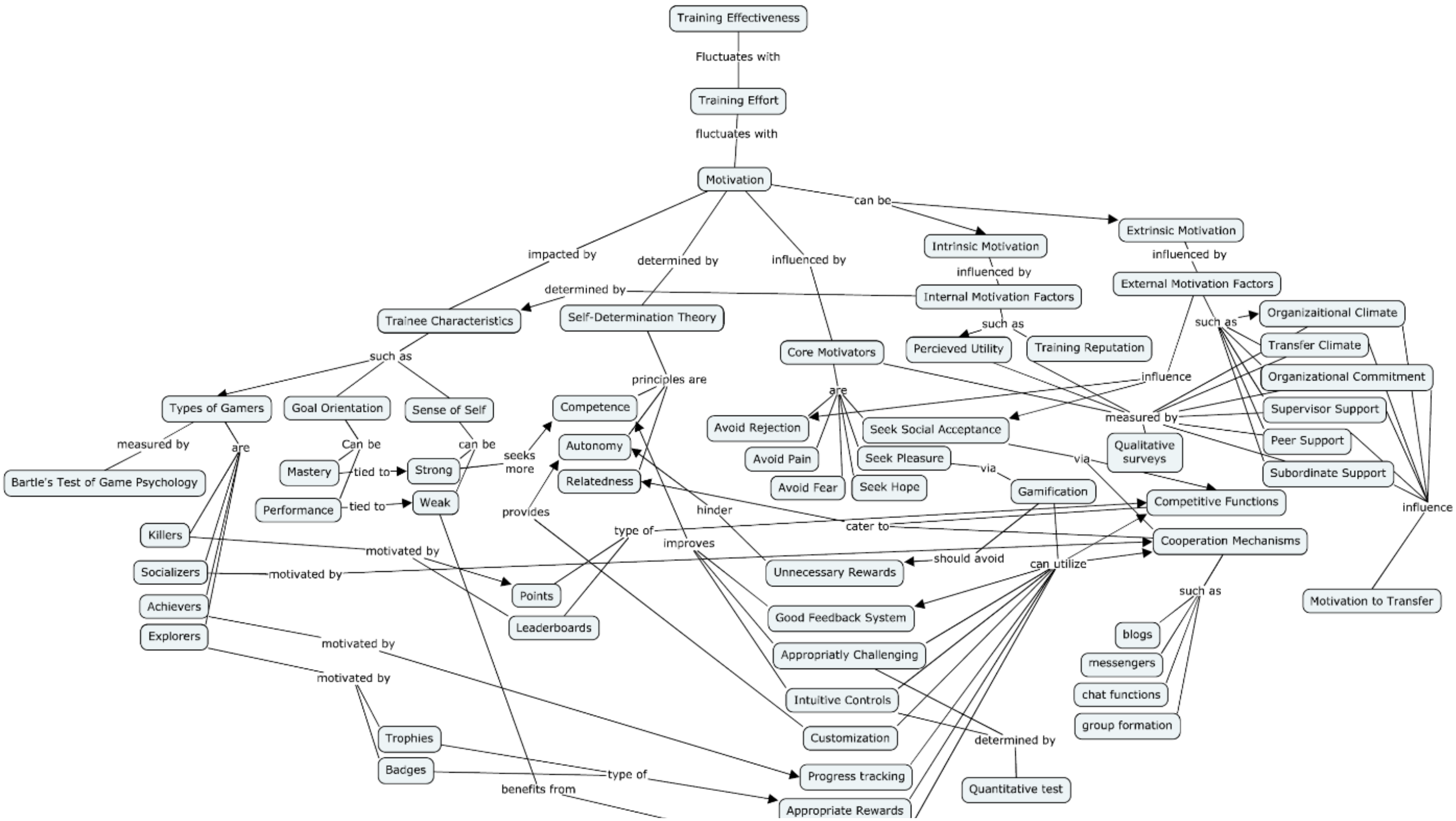

Figure 6 Motivation Concept Map

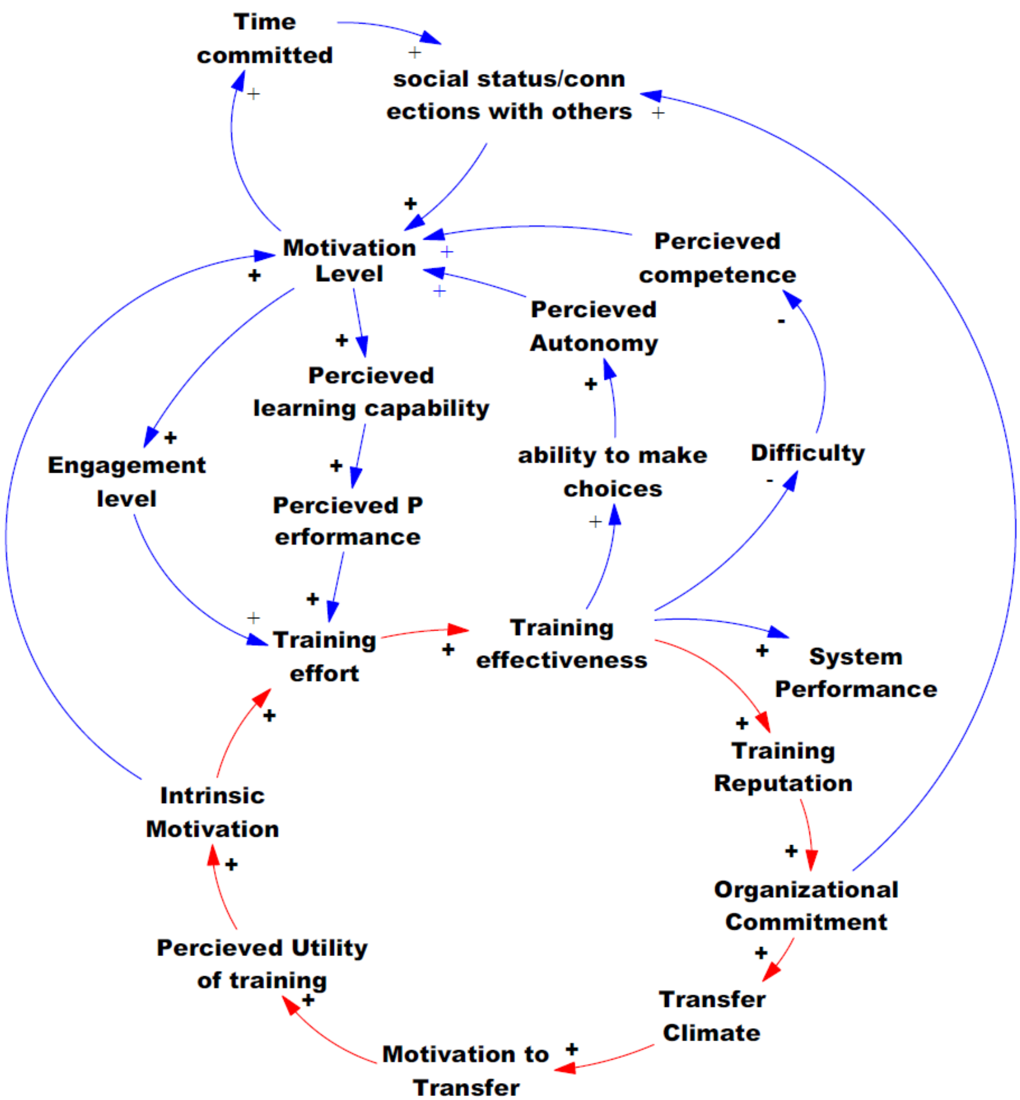

Figure 7 Causal Loop Diagram of motivation in training

In addition to the CMAP a CLD, shown in Figure 7 was created to understand how the various motivators work together. The CLD represents both short-term, i.e., day to day influences, as well as long-term influences. Short term influences are represented by the blue arrows while the long-term influences are represented by red arrows.

Figure 7 highlights how various facets of short-term motivation may be used to motivate different people. As organizational commitment improves, the social connection students build with one another will improve. This can be achieved by incorporating chat functions, group formation, and blogs into the game. Socializers will find the improved social connection appealing and will experience an increases motivation level and therefore put forth more training effort. Killers, or students that prefer to compete, will experience improved motivation and put in more training effort as their perceived performance rises. Performance can be tracked using point systems and leaderboards in game. Levels could also be repeated to allow students to attempt higher scores or explore new avenues of play for students with the explorer personality. As students are provided freedom to make choices their perceived autonomy will increase their motivation level. Autonomy could be provided through customization of displays and profiles. As the perceived difficulty of the course increases and students feel less competent their motivation level will decrease. Difficulty could be adjusted by providing hints on how to complete task such as performing various maneuvers.

Motivation level is the focus of the short-term motivation loops, indicated by the blue lines, that leads into the long-term motivation loop, indicated by the red lines. The CLD shows that as motivation level improves the perceived learning capability of the student also improves. As the learning capability improves the perceived performance of students will also improve and cause them to put forth more effort in training. As training effort improves training effectiveness will improve which leads to a better training reputation. As the training reputation gets better the organizational commitment to the training will rise and lead back to the short-term loop of social connections improving motivation level. Organizational commitment will lead to the transfer climate within the organization being more welcoming of the information taught in the training. With the transfer climate getting better the student motivation to transfer what they learn to the workplace will improve. This leads to the perceived utility of the training growing within students and their intrinsic motivation to learn growing which has a short-term impact of improving motivation. Improved intrinsic motivation leads back to increasing the training effort which starts the loop anew. The loop will reinforce itself over time.

Combined domain requirements

With the domain knowledge about space and motivation compiled the combination of requirements was put into a lesson plan shown in Figure 8**.** built in a block definition diagram on Cameo systems modeler. The diagram shows that to build up to complex topics, prerequisite topics should be covered first. The space domain lessons should include the fundamentals of orbital motion, thrust, orbital engagements, mission planning, limitations and constraints, and fulfilling military objectives respectively. Most of the motivation requirements apply throughout the course such as telling students what they will learn, demonstrating what they should do, allowing them to practice the new knowledge, providing feedback, and allowing students to socially engage with their peers. Students should also be allowed to customize their learning experience. Before students begin the course, their psychological characteristics should be determined. Knowing the characteristics of each student allows for variable rewards to be provided. The game controls need to be intuitive to ensure that students can focus on learning about space operations. As students learn the challenge level needs to match their progress.

All these requirements come together in the activity diagram shown in Figure 9., which shows that the personality test should be administered at the start of the class. The personality test is used to provide students with incentives that fit them. The first topic is then introduced, students are informed what they are expected to learn, and they are provided a demonstration of the proper use of the knowledge, skills, and abilities. Next students are given the opportunity to practice the KSAs, customize their learning experience, and engage with their peers. Students are then given feedback and assessed on their mastery of the KSAs. If the mastery level is acceptable students are rewarded according to their characteristics and a layer of complexity is added to the course. Some incentives such as the ability to socialize or customize displays are available throughout the use of the game system, however, other rewards like giving peers the opportunity to congratulate one another and giving students the option to replay levels for the chance to improve scores with higher difficulty or explore utilize new strategies is reserved for after students have shown that they understand the material at an appropriate level. The cycle then starts again with the next topic or ends if the final topic has been taught.

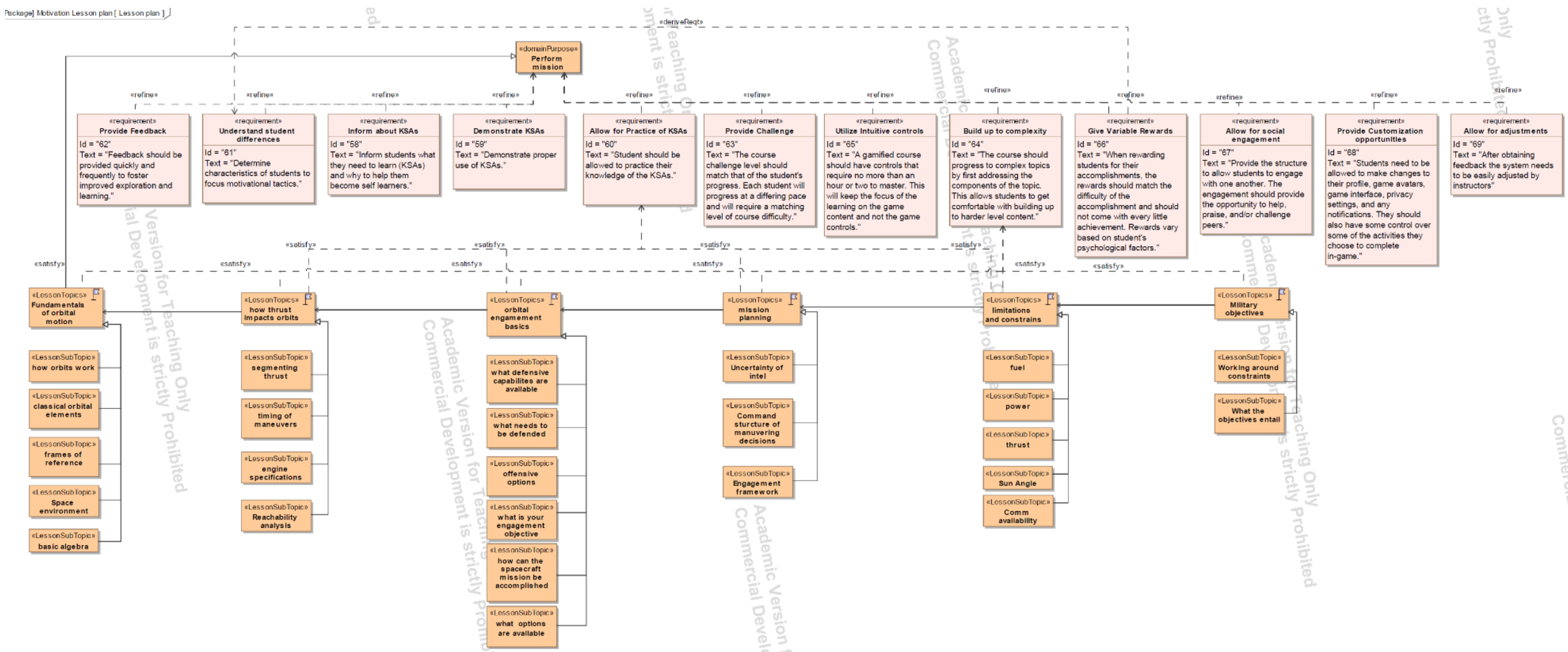

Figure 8 Block Definition Diagram of Lesson Plan for space operator training

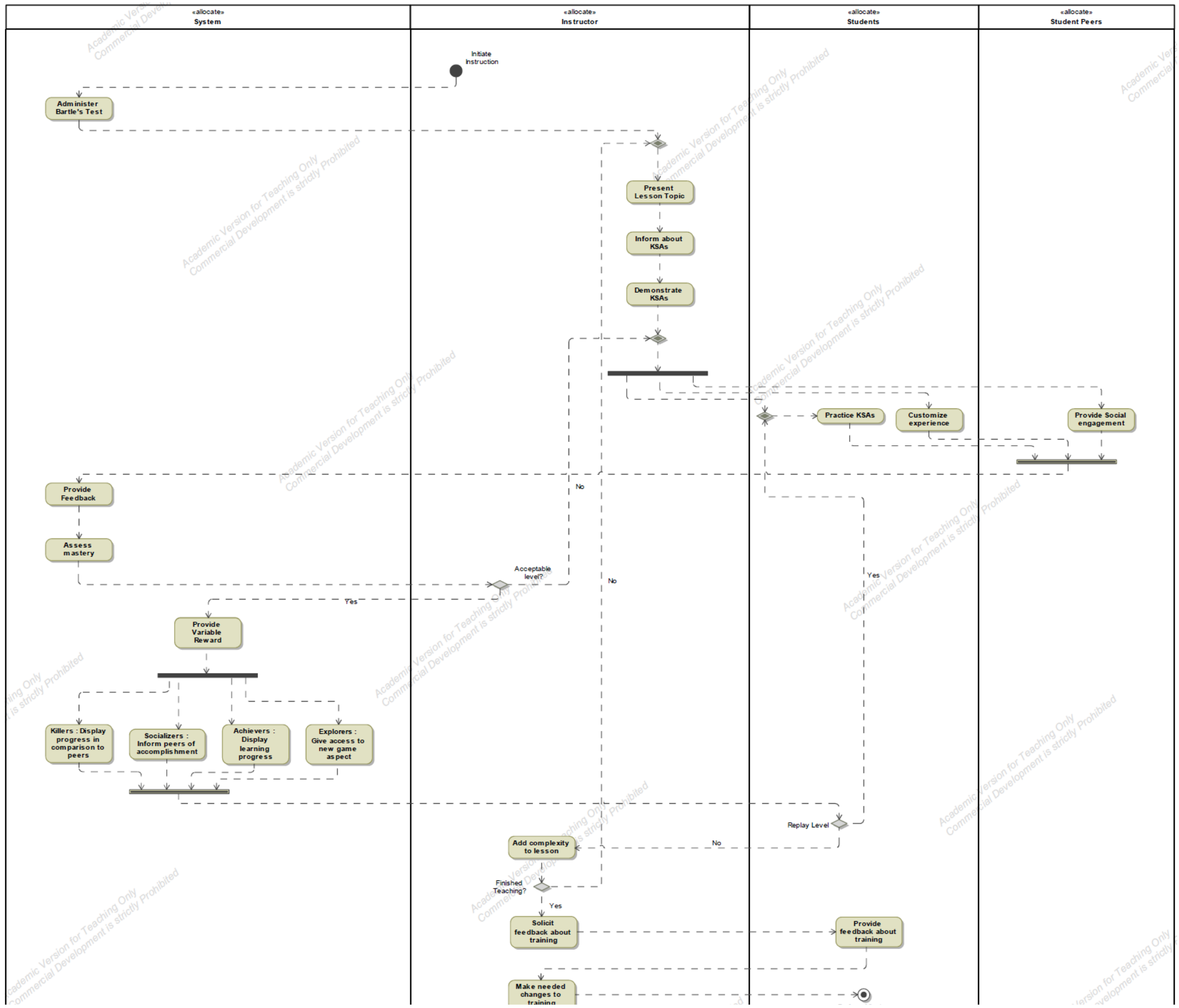

Figure 9 Activity Diagram of Course flow

Chapter Summary

This chapter discussed what space operators need to know to be successful in their jobs as discovered in the space domain knowledge gathering process. The goals and roles of the space domain were then identified. Next the process of motivating space operators was discussed. The process of generating long term motivation and short-term motivation was also covered. The knowledge that space operators need to be successful was then combined with the motivation principles to come up with a lesson plan that could train and motivate space operators. The process of utilizing the lesson plan was then described. The next chapter summarizes the research findings.

V. Conclusions and Recommendations

Chapter Overview

This chapter will review what students need to know to conduct their satellite operator roles and how motivation for learning within a game environment can be stoked within students during the training process. Answers to the research questions posed are then reviewed. Recommendations for what needs to be accomplished following this work to further refine the method proposed are included. Recommendations for other topics that need to be explored are also discussed. The significance of this research to the future of space operations is then discussed.

Summary of findings

A gamified system is suggested as the medium for implementing the training of proximity operations within the space domain. The current research suggests that a professionally designed, gamified system can provide rapid and customized feedback that allow students to practice the knowledge, skills, and abilities they need to master to support proximity operations. Further, such a game can provide a setting that alleviates the fear of detrimental consequences that can occur when students experiment with novel strategies within a classroom environment. Such a system would need to fulfill the role of intel analyst and mission manager to aid in representing the operational environment for satellite operators.

The results document the skills that space operators need to master to fulfill their role in proximity operations to be successful in conflict. Operators must know how to maneuver in space which involves understanding orbital motion and how thrusting will impact an orbit. Operators must also understand the basics of the space environment which involves the forces acting on a spacecraft at different orbital regimes and the natural concerns that accompany them such as drag, radiation, and debris. Students must understand the constraints of spacecraft such as onboard fuel, battery health, and thruster capabilities. At least basic algebra and the ability to read plots and graphs is needed to understand the movement of objects in space by students. Students should be taught that decisions are made by teams and are based on the satellite's mission, risk tolerance of the team, and other factors. Operators get intel from ground and space-based sensors and that information becomes less reliable as the age of the information increases. Information can also come from intelligence squadrons about other space objects, but that information may be contradictory, incomplete, or inaccurate.

Research revealed that space operators can be motivated to learn in training and that self-learning can be encouraged. Motivation can be influenced by understanding and adhering to the core motivators, self-determination theory, and trainee characteristics. The core motivators are to avoid rejection and seek social acceptance, avoid pain and seek pleasure, and to avoid fear and seek hope. Self-determination theory states that as students feel more competent, are granted more autonomy, and have a sense of relatedness to others, their motivation will rise. Adjusting the difficulty of training can improve competence and give students hope. Allowing students to customize their training experience will improve their autonomy and provide an avenue for students to seek their own pleasure. Providing a method for students to help, challenge, and congratulate each other will help students feel more related to and accepted by their peers. The course difficulty and student engagement level are part of the short-term gains in building motivation. Building long-term motivational gains will generate intrinsic motivation which can lead to students putting forth more training effort and improving the effectiveness of the training. Intrinsic motivation can be cultivated by improving the training reputation, organizational commitment, transfer climate, motivation to transfer, and perceived utility of the training. Improving intrinsic motivation can also lead to learning outside of the structured learning and result in self-learning from students. Trainee characteristics can augment space operator learning and be used to provide variable rewards such as providing competitive opportunities, social interaction, achievement tracking, and the ability to explore and learn beyond the structured course. Trainee characteristics can be determined by administering personality tests such as the Bartle's test of game psychology and the results of this test can be used to understand how best to motivate individual students. Goal orientation and a student's sense of self can also impact how they apply themselves to their studies. A student who is uncertain of their purpose for attending the training will be less motivated than a student who has a firm grasp of what they need to learn and why they need to know it. Giving students a strong sense of what they need to do by ensuring they understand how the KSAs they are to be taught will impact their performance and understanding of a job they value will result in students that seek to master the material rather than perform the needed actions solely to obtain a desired grade. Surveying students to determine how they feel about the utility of the training, whether the organization is accepting of the training in the workplace, and the state of their core motivators will allow for adjustments to be made to the training over time. The adjustments can include ensuring the information taught matches the utilized KSAs of the space operations squadrons or giving students avenues to build confidence with the KSAs being taught. The system should allow for instructors with some instruction to adjust the training as needed.

Recommendations for Future Research

This thesis has proposed models for games to facilitate space operator training and motivation. Future research should focus on validation of these models. The model of motivation merged recommendations from various theories and this validation is necessary to ensure that there are no inconsistencies from this merging of theories. One method for achieving this would be to use the models to evaluate current games which provide varying levels of motivation to determine if the models provide consistent grading of motivation. Evaluating current games would also allow for the chance to determine if the motivation theories work as intended when combined. The space operator training model could also be used to evaluate various games intended for space operator training to determine the degree to which the model differentiates various options.

The current proposed system needs to be evaluated. Kirkpatrick's four levels of evaluation indicates an intriguing method for doing this. First obtaining student reaction to the training could be accomplished by way of surveys. Evaluations of what students have learned via testing could then take place. The behavior of students could be studied in the workplace to determine if the KSAs taught are being utilized. Finally, the results of the organization can be evaluated to determine if the training has generated the desired improvement (Kirkpatrick, 1994).

A system can also be developed to implement the proposed requirements. This system will need to adhere to the motivation requirements while teaching the space domain requirements. This system can start as a single player and player verses player game that eventually grows into a multiplayer game. A multiplayer game could then be utilized as a continuous training tool for space operators beyond the structured learning experience that allows them to constantly practice and learn tactics while challenging other space operators throughout the U.S. Space Force.

The overall framework could alternately be used to evaluate current space operator training tools to determine how well they are performing when compared to what has been suggested. The use of this framework as an evaluation tool could lead to the development of other training tool frameworks for different career fields in the DoD.

Recommendations for future work

The user interface used by various space operations squadrons differs as do the tools used. Research can be done to unify the interfaces so that the interfaces used at training or previous jobs can be used to reduce learning times for follow on assignments. This work would require reaching out to various units with the goal of determining what information they would need to fulfill their mission. Therefore, research, such as that performed by Oryschak, who attempted to determine information requirements for defensive satellite operations, could be used as a springboard for future research (Oryschak, 2020).

Significance of research

DoD space assets were once considered safe from threat due to the expense and difficulty associated with reaching them. Now U.S. adversaries are proving that the sanctuary space once was is no more. Should a conflict arise, the adversarial forces will likely be drawn to attack targets that are unprotected and vital to the military power of the U.S. DoD. This new reality of a contested environment will need to be instilled into students that will be charged with protecting these space assets. Part of that task will involve learning about threats and appropriately reacting to them as they arise. Students who are motivated to continue learning and growing as space operators will perform this duty to a higher degree. This thesis sought to apply learnings from the motivation domain to the space domain by developing guidelines that a gamified system could use to teach space operator students. With the findings from this research space operator students will be better trained in defending the assets that enable worldwide commerce, communication, global positioning and tracking, intelligence, and more to small businesses and the U.S. DoD.

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 074-0188
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1. REPORT DATE *(DD-MM-YYYY)* 25-03-2021	**2. REPORT TYPE** Master's Thesis		**3. DATES COVERED** *(From – To)* October 2019 – February 2021
TITLE AND SUBTITLE Guidelines for a System that Builds Motivation in Space Operator Rendezvous and Proximity Operations Training			**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Davis, Foster E., Captain, USAF			**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/ENV) 2950 Hobson Way, Building 640 WPAFB OH 45433-7765			**8. PERFORMING ORGANIZATION REPORT NUMBER** AFIT-ENV-MS-21-M-215
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Intentionally left blank			**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
12. DISTRIBUTION/AVAILABILITY STATEMENT **DISTRUBTION STATEMENT A.** APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.			
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14. ABSTRACT Services provided by spacecraft, including communications and global positioning, are integral to small businesses, multinational corporations, and the United States Department of Defense. United States rivals recognize the need to undermine the military advantage provided by the space domain and are exploring ways to degrade these services in their warfare doctrine. In response, the United States will need space systems suited to counter these threats and personnel who are trained to respond to the new reality of a contested space environment. This paper characterizes the knowledge, skills, and abilities needed for operators to engage in rendezvous and proximity operations. This paper also reviews the academic literature and written guidelines for developing motivation in an interactive environment for improving space operator training.			
15. SUBJECT TERMS Space, training, motivation, gamification, framework			

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Michael E. Miller, AFIT/ENV
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*
U	U	U	UU	59	(843) 655-2276 Foster.davis@afit.edu

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