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Learning Satellite Operations by Play - Gamification for Spacecraft Operations Training of Subsystems Knowledge and Control Room Proceedings on the example of EDRS-C

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Abstract

Classic training methods for satellite operations engineers consist of studying the documentation, training on the spacecraft (S/C) simulator, control room simulations with the whole team and participation in S/C activities as a trainee. While studying the documentation is a necessary step, it is also the least engaging part of every training. Training on a S/C simulator or even control room simulations can provide valuable breaks in the training plan. Unfortunately, those activities are not always possible as some S/C simulators need to run on specific hard- or software, limiting the number of people who can train on a S/C simulator simultaneously. This is also true for the availability of control room simulations as they require in most cases the entire S/C operations team as well as considerable preparation time on part of the simulation officer, who needs to craft anomalies and configure the simulator. Activities on the actual satellite in turn are the most hands-on experience a trainee can get. However, S/C anomalies often can't be predicted in advance, so only planned or routine activities can reliably be used for hands-on training. With the increasing number of automations on modern S/C on the other hand, the number of tasks routinely performed by engineers are decreasing in numbers and therewith the training possibilities.

Providing a more accessible way to test and refine the learned S/C subsystem knowledge this paper as part of a qualitative pilot study, proposes an innovative board game-based gamification addition to the conventional training method of S/C subsystems for new engineers. It evaluates the impact on the aspects of entry barriers, self-motivation and consolidation of S/C operations knowledge. The gaming aspects incorporated in this board game-based training addition consist of peer interaction, immediate rewarding, character development, low barrier to entry and risk-free interaction with the material. While the board game proposed is adaptable for different types of spacecraft, the prototype used in this paper is based on the EDRS-C satellite.

In this qualitative pilot study, the board game was tested by six participants in regard to its playability, its low entry barrier, its transfer of knowledge and its effect on the participants motivation to engage with the topic further.

With only this small sample of test subjects, the game shows promising results and engages the players while being fun and motivating the participants to expand their knowledge significantly in the topic of payload operations.
Keywords: training, gamification

Acronyms/Abbreviations

Packet Utilisation Standard (PUS),
Attitude and Orbit Control Subsystem (AOCS),
Thermal Subsystem (THM),
Power Management Subsystem (PWR),
German Space Operations Center (GSOC),
European Data Relay System (EDRS),
European Space Agency (ESA),
Optical Inter Satellite Link (OISL),
Highly Adaptable Satellite 3 (HYLAS),
Next Generation Radiation Monitor (NGRM),
Telecommand (TC),
Spacecraft (S/C),
Experience points (XP),
Telemetry (TM),
Ground (GRD),
Digital Processing Unit (DPU),

Graphic User Interface (GUI),
Flight Operations Procedure (FOP),
German Aerospace Center (DLR),
Nord Atlantic Treaty Organization (NATO).

1. Introduction

Training of new engineers for spacecraft subsystems is often a long and tedious process with little to no practical experience for the trainee, especially at the beginning of the training phase. These kinds of trainings consist mainly in self-study of documentation, with sessions on simulators later in the training. In order to enhance this experience and to shorten the time needed from start of training until the certification as a subsystems engineer, this paper proposes an added innovative gamification approach to facilitate the spacecraft operations training alongside the classic training methods. Gamification is the application of game elements to other areas to encourage commitment and increase motivation in the participants. In turn, a serious game uses gamification approaches to teach concepts or knowledge by making the interaction with the source material fun, while not having entertainment as its main goal [1]. Such games have proven to be effective tools to enhance learning experiences and increase motivation for self-study [2]. Since the first introduction of the term "serious games" by Clark C. Abt in his identically named book in 1970 [3], it is heavily intertwined with the aerospace sector. One of the earliest digital serious games was the Microsoft Flight Simulator released 1981, which aims to teach the intricate profession of flying a plane by using abstractions [4].

Since the early days of serious games in flight simulators, various types of games were invented and used to further interests and ease entry level barriers in order to grasp complex or monotonous topics. Reaching from simple board games like "Telling the time" to teach children how to read an analogue clock, over software applications like "A Portable Learning Application" to train astronauts on long duration missions [5], up to high quality 3D games like "Microsoft Flight Simulator" to teach flying a plane.

In satellite operations, extensive training is necessary in order to allow an engineer to command and trouble shoot the different subsystems of a real satellite. While the standardisation of satellites is advanced and standards like the "Packet Utilisation Standard" (PUS), which defines frameworks for satellite communications [6], are implemented on an increasing number of satellites, there are still many different platforms and payloads. With such a diverse field of systems, the amount of training a new subsystems engineer must complete before being capable to take over normal operations or even anomaly handling is high. Even if the basic functionalities of systems like Attitude and Orbit Control (AOCS) or Power (PWR) & Thermal (THM) are similar on most platforms, satellite specific knowledge is still required.

The German Space Operations Center (GSOC) is flying multiple satellite missions at the same time. With an efficient use of staff, it is common that an engineer has to be trained on different satellites with differing platforms in many aspects. While digital simulators are part of the training process, satellite simulators are often custom software created for a specific satellite and need to be installed in an operations environment. This in turn leads to a bottleneck in available training resources because some simulators only run on one or two machines at the same time. While the study of documentation is a necessary part of the training, it is also tedious and provides no hands-on experience like a simulation would.

In order to reduce training duration and break up conventional subsystem engineering training that mainly consists of self-study of large documents, an added gamified training method was developed at GSOC for the European Data Relay System C (EDRS-C) mission in form of a serious game realized as a board game called "Operation Payload". The EDRS-C satellite is a data relay satellite equipped with two communication and one radiation measurement payloads. It was launched in 2019 as part of the EDRS program and is operated by GSOC [7]. The satellite uses the SmallGEO platform developed by OHB. Its main task is to perform laser links with other satellites and send their data to the ground. Its main customer at the moment are the Sentinel satellites operated by the European Space Agency (ESA) as part of the Copernicus program [8]. The board game approach called "Operation Payload" was implemented as an addition to the nominal EDRS-C payload training. It provides an enhanced examination [9] of the topic.

2. Serious Game "Operation Payload"

The serious game "Operation Payload" was developed to simulate anomaly handling for the EDRS-C payload subsystem. It simulates abnormal behaviour of the satellite which needs to be addressed and corrected if possible. The EDRS-C payload subsystem consists of three separate payloads, Optical In-orbit Satellite Link (OISL), Highly Adaptable Satellite 3 (HYLAS) and Next Generation Radiation Monitor (NGRM). OISL and HYLAS are communication payloads, while NGRM is a radiation and heavy ions measurement device. Based on the documentation and past anomalies of all three payloads, certain problem cases, as well as recurring basic requests (BR) which are requests by the customer to change the satellite configuration, were selected to be represented in the game by reducing them to the core problem and by using abstraction to bring them into a game environment with a limited decision space.

The problems were implemented as so-called anomaly cards in the board game. The main objective of the board game is to analyse the anomaly, identify the responsible component and describe the steps needed to solve the problem if there are any, and at the same time to keep the payload operational. While most anomaly cards only have one corresponding component that is at fault, some anomalies are more complex and are a result of multiple failures. In contrast, other anomalies only appear like problems but can be ignored or are a result of external factors that are outside the space of action of a subsystems engineer. If the players accumulate a total of eight active anomaly cards at the end of a round, they lose the game.

The goal of the game is to keep the satellite running long enough, to fulfil its mission. In case of EDRS-C, the execution of 100,000 link sessions via its OISL payload was chosen. The number is somewhat arbitrary for the use in the game. All players work in cooperation for solving the satellite anomalies, by playing action cards, which are put on the board in the stack area (see Fig. 1). Most of the action cards are based on telecommands (TCs) that can be send to the spacecraft (S/C) or different ground activities like switching to a back-up ground station. If an anomaly is solved successfully by playing the correct action cards, the players receive a certain number of experience points (XP) based on the difficulty of the solved anomaly. The players can then exchange these XP for new advanced action cards that are more efficient in solving anomalies or allowing the players new approaches for problem solving.

Fig. 1. “Operation Payload” game board including spaces for anomaly, action and system cards as well as the progress bar.

If the players cannot solve an anomaly, they are penalised depending on the urgency of the anomaly. If the players played wrong cards to solve an anomaly, they are penalised as well by having to draw one extra anomaly card in the next round.

In order to simulate the engineer checking telemetry (TM), a barcode-based system realized by yellow bars on the cards, was introduced (see Fig. 2). A player can compare the barcode of an anomaly with different system cards, representing the hardware components of the S/C or ground (GRD) systems. If the barcode on the anomaly fits all short bars on the system card when compared, a component corresponding to the anomaly is found and can help the players to figure out what the underlaying problem is.

To achieve this, each systems card was given its own unique code during the design process. The code is comprised of eight possible locations for the yellow bars on the system cards and eleven possible locations on the anomaly cards. It can be represented by a binary number with zero equal to no bar and one equal to a bar. The code on system cards or system-code can be separated into two segments.

The first segment includes four digits of the code, describing the subsystem the system card is associated with. For example, the Digital Processing Unit (DPU) would be associated with the OISL subsystem. The second code segment is also comprised of four digits, describing the component in the subsystem, in this example the DPU itself. The last segment, that only the anomaly cards have, is comprised of three digits and corresponds in most cases to one of three condition texts on the system card. These contain details about the condition the component is in right now or, in case the component is offline, the TM received shortly before the component was shut down.

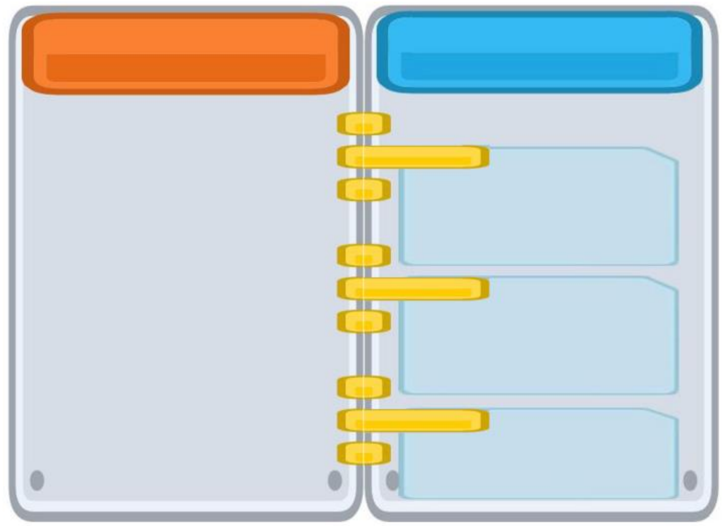

Fig. 2. Barcode (yellow) comparison between a blank anomaly card on the left (orange) and a blank system card on the right (blue).

An anomaly matches a system card, if the anomaly-code is equal to one on all the same spots as the system-code of the compared card. For example, the anomaly code 01110010100 would correspond to the system card DPU with the code 0X110X101X0.

For payload training purposes the following subsystems were defined in "Operation Payload": OISL, HYLAS, NGRM, payload general and GRD. Payload general and GRD were chosen because they can interface with payload operations. For clarity reasons two bits are used for the identification of the subsystem segment of the code and also two bits for the identification of the component segment of the code. With such a system, six distinct subsystem areas can be defined as well as six components per subsystem, resulting in 36 different possible subsystem cards, which is sufficient for the representation of the abstracted payload system structure of EDRS-C.

Fig. 3. S/C model for player resources.
Yellow cubes are not used in the current version.

Player stakes are represented by a model of the S/C with small plastic cubes (see Fig. 3) visualizing available power (red), available bandwidth (grey) and available redundancy (blue). Power is the resource players need to use in order to keep the payloads running and progress the game. Bandwidth is used to limit the decisions space of the players by allowing them only a certain number of TCs to solve any given anomaly, as each TC requires a fix amount of bandwidth available. Redundancy tracks the success of the players in solving anomalies before they become critical. It functions as an alternative lose condition.

If an anomaly is not solved at the end of a round, the anomaly card is flipped over. On the backside four types of information are given, a short text describing the root cause, the required actions to solve the anomaly, the amount of XP gained if the anomaly is solved and the penalty if the anomaly is not solved. By this method, the players know the steps necessary to solve the anomaly next round, but have to face the consequences of the penalty the card describes. For persons with little to none experience in the topic, a lookup table with acronyms is provided.

3. Theory and Design Decisions

Different forms of information sources to enhance the players knowledge of the topic are incorporated into "Operation Payload". While the main objective is to teach anomaly handling in a risk free and engaging environment, other secondary objectives are incorporated as well. The familiarisation with relevant acronyms is one of the secondary objectives. Over thirty-five acronyms are used in the scope of the game. While each one is introduced at least once, repeating the acronym in other places forces the players to learn its meaning. Another objective is to create bridges in the players heads between certain parameter behaviours and alarms, and their likely corresponding root causes. For this, pictures were added to the anomaly cards with typical plots for the corresponding root cause of the anomaly if available. This also familiarises the players with the Graphic User Interfaces (GUI) of the tools used in satellite operations of EDRS-C. The last objective incorporated is the inclusion of flight operations procedures (FOP) which are used in daily operations.

FOPs are a collection of TM checks and TCs to achieve certain tasks on a S/C. These FOPs are beforehand discussed with the manufacturer and the customer and provide agreed upon sequences of TCs that can be requested by the customer to be executed. It is essential for a subsystem engineer to be familiar with the FOPs belonging to the subsystem they are responsible for. For the incorporation into the game, so called advanced action cards (see Fig. 4) were introduced that include some of the names and purposes of EDRS-C payload FOPs. While it is possible to operate the S/C by searching the corresponding TC for each task or anomaly, the consolidation into FOPs is adviced and helps the players to handle the amount of TCs needed to resolve S/C anomalies.

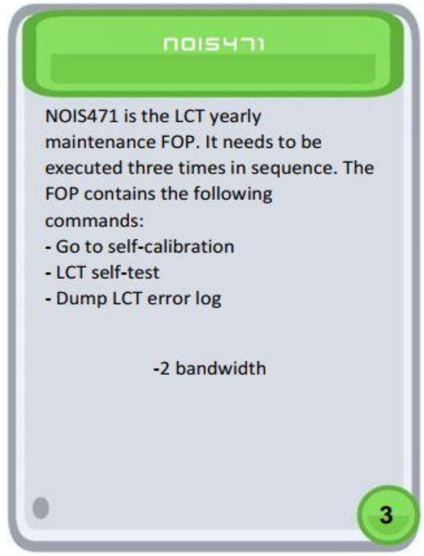

Fig. 4. Advanced action card for FOP NOIS471

Optional rules for in-game communication were proposed to train the typical speech patterns in a control room setting, to increase the immersion and add further skill training to the game.

4. Test Campaign

The game "Operation Payload", as part of a qualitative pilot study, was tested on a small number of participants to gather data about its effectiveness and potential for training purposes. Six persons participated in the study. The participants were given a two pages long questionnaire to test their already existing knowledge about the topic. They were given fifteen minutes to answer questions about their knowledge of the relevant acronyms and the general function of the EDRS-C payload. The participants should name the meaning of thirty-six acronyms, name all payloads hosted on EDRS-C and describe their main functionality, name other subsystems that interacts with the payloads on a regular basis as well as describe a few of the operational software products used in the EDRS-C mission. Following this the participants were introduced to the game and were taught the rules. They played the game for a time period of about two hours and immediately after had to fill in the same questionnaire again.

By comparing the answers to the questionnaire from before and after the participation in the game, the amount of acquired knowledge could be measured. In total, a participant could reach 86 points by answering all questions correctly. One additional question for the participants to rate their motivation was asked after the game.

Two of the participants were fully certified payload engineers. Three were aerospace engineers but not certified as payload engineers and one test subject didn't have any engineering training. Four of the participants were female, two were male. The participants played the game in pairs of two. During the game, one person played with only action cards for OISL while the other person played with only action cards for HYLAS and NGRM. The GRD and PLD general cards were split between both participants.

5. Results

The questionnaires were analysed and each correct answer was given one point. The results of the questionnaires were plotted in Fig. 5 with the points the participants reached before playing the game marked in orange and the points they reached after playing the game marked in blue.

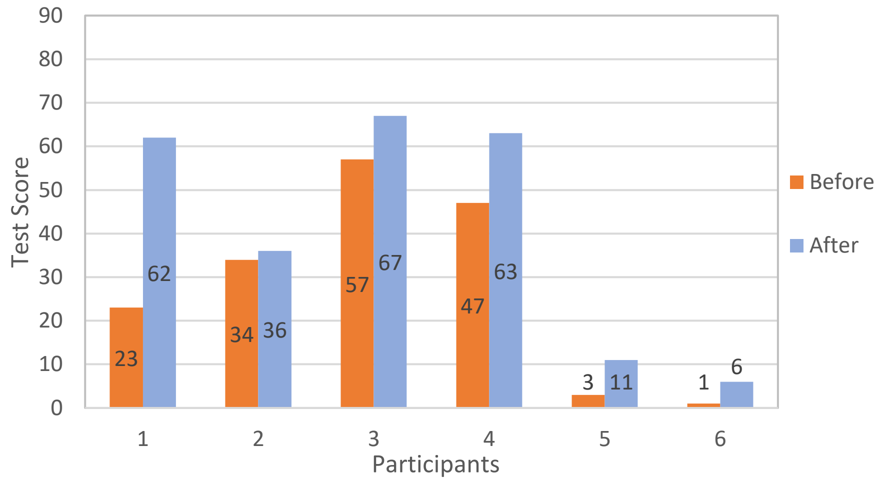

Fig. 5. Questionnaire results of the six participants before and after playing "Operation Payload".

The participants improved their results on average by $15.12\ \%$. To test if the average improvement was significant, a paired sample t-test was performed [10]. To be able to compare the t-value with available t-tables, a significance level α needed to be defined. A common value for α is 0.05 which is also used for this evaluation.

With the calculated t-value $t(5) = 2.662, p < .05$ a comparison with standard t-tables can be made (see appendix t-table). With $2.662\ > 2.571$ the test delivers a significant difference between the scores of both questionnaires.

After the participants completed the second questionnaire, they were asked to rate their motivation to engage in the topic further on a scale from one to five. All participants answered this question with a five.

6. Discussion

After testing the serious game approach "Operation Payload" in this pilot project, a significant increase in payload subsystem knowledge was found. The interaction of the participants with the material is high and no motivational fatigue could be observed in the test period. Even participants with no prior knowledge in the topic of payload operations on EDRS-C, showed interest and could improve their test scores by playing.

For a successful serious game, two aspects need to be fulfilled. The source material needs to be transported and internalized by the players, while on the other hand the game needs to be fun to further motivate and invite the players for future interactions. Based on the limited data available, both aspects were fulfilled. All participants described a high motivation after playing the game for two hours and were willing to play the game again in the future. The knowledge transfer worked, as most participants showed an improvement of test scores after playing the game.

The transfer of complex problems into the restricted space of the game, allows to present already schematized information to the players. This reduces the load on the working memory [11] and increases in turn the efficiency of the knowledge transfer.

A quantitative study is needed to prove if the addition of this serious games approach improves operational knowledge of subsystems engineers and shortens their training duration. While the results of this qualitative pilot study are promising, the number of participants was too low to achieve reliable results.

As the topic of payload operations on EDRS-C is a very limited field, other similar gamification training additions for different subsystems or other S/C platforms would be possible. In that, the game "Operation Payload" provides a framework for other serious games in the area of S/C operations training with a focus on anomaly handling. Further improvements of the basic game structures are possible. The rules of the game could be streamlined to lower the barrier of entry further and reduce the initial time necessary to read and understand the rules. Another improvement could be the inclusion of rules regarding operational style speech patterns and use of the NATO phonetic alphabet. This would work best by having other players responsible for different satellite subsystems on the same table to coordinate with. An increase in the scale of abstraction, in sense of a more general approach on the topic, from the technical level to the game level, could make the game more accessible to a broader audience. This in turn would increase the abstraction of the transported knowledge. With such a modification, the focus of the game from teaching the root causes and possible solutions of known anomalies would shift to a more general problem-solving approach in S/C operations.

7. Conclusions

The proposed serious game “Operation Payload” shows promising results with regard to player engagement and motivation. Further studies over a longer period of time and with more participants are needed to get reliable results regarding the possible reduction of training duration for S/C operations engineers. The game provides a fun and hands on break from pure reading of documentation and will be tested further.

Appendix t-table

Table 1. t-values based on [10]

cum. prob	$t_{.50}$	$t_{.75}$	$t_{.80}$	$t_{.85}$	$t_{.90}$	$t_{.95}$	$t_{.975}$
one-tail	0.50	0.25	0.20	0.15	0.10	0.05	0.025
two-tails	1.00	0.50	0.40	0.30	0.20	0.10	0.05
df							
1	0.000	1.000	1.376	1.963	3.078	6.314	12.71
2	0.000	0.816	1.061	1.386	1.886	2.920	4.303
3	0.000	0.765	0.978	1.250	1.638	2.353	3.182
4	0.000	0.741	0.941	1.190	1.533	2.132	2.776
5	0.000	0.727	0.920	1.156	1.476	2.015	2.571
6	0.000	0.718	0.906	1.134	1.440	1.943	2.447
7	0.000	0.711	0.896	1.119	1.415	1.895	2.365
8	0.000	0.706	0.889	1.108	1.397	1.860	2.306
9	0.000	0.703	0.883	1.100	1.383	1.833	2.262
10	0.000	0.700	0.879	1.093	1.372	1.812	2.228

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