Gamification for Astronaut Training

Ferdinand Cornelissen[1]
Nspyre B.V., Utrecht, The Netherlands

Mark A. Neerincx[2], Nanja Smets[3]
TNO Human Factors, Soesterberg, The Netherlands

Leo Breebaart[4]
Science & Technology Corporation, Delft, The Netherlands

Paul Dujardin[5]
NLR, Marknesse, The Netherlands

and

Mikael Wolff[6]
ESA / ESTEC, Noordwijk, The Netherlands

This paper reports on the use and the evaluation of applying gaming aspects as a means to promote self-study and increase motivation to train for executing operations on human space flight missions that have a duration that exceeds the typical duration of low earth orbit missions. The gaming aspects that are evaluated include avatar representation, leaderboards, short 'quest' lessons, immediate rewarding, the notion of achievements, the structuring of training content using a skill-graph, and character development. These aspects are implemented in a prototype that integrates training execution, monitoring and evaluation. Subsequently, the prototype is used to evaluate the applicability and efficiency of gaming concepts for training. The evaluation is based on a structured walkthrough, where participants are guided and questioned while using the prototype in a predetermined way. In general, the results indicate that the use of gaming aspects have a positive impact on self-study and motivation. In particular the structuring of training content and the character development that is linked to it invites to train more. However, rich training material should be coupled tightly into the gaming aspects in order to achieve these results. This study provides an initial step into applying gaming aspects for astronaut training. More research should be done to further study the applicability of this approach.

I. Introduction

Today's astronauts are on a tight schedule, both in orbit as well as during the preparation phase of a mission. The preparation of a mission includes a strict training program in a class-room environment, focusing on maximum efficiency of the mission outcome. However, for future astronauts on manned missions beyond low-earth orbit the duration of the mission will likely be more than two years. The scope of the actual mission and the experiments performed will subsequently exceed the scope as anticipated during the mission preparations. On these missions, a shift of autonomy from ground to in-flight training by the crew is expected, and therefore astronaut training needs to

[1] Technology Officer, Nspyre B.V., ferdinand.cornelissen@nspyre.nl.
[2] Senior Research Scientist, TNO, mark.neerincx@tno.nl.
[3] Research Scientist, TNO, nanja.smets@tno.nl.
[4] Software Architect, Science & Technology Corporation, breebaart@stcorp.nl.
[5] Senior Researcher, NLR, paul.dujardin@nlr.nl.
[6] Technical Officer, ESTEC Systems, Software and Technology Department, mikael.wolff@esa.int.

be adapted accordingly. The extensive duration of the mission, the delayed communications due to distance and potentially limited line of sight, the autonomy shift, as well as on-going changes in the mission goals, the environment, and the tools at hand, all imply a need for self-study, motivation, and a means to provide dynamic training content *during* the mission rather than only *before* the mission. APLA (*A Portable Learning Application*) is a study performed for the European Space Agency to identify and fulfill these needs. The study is based on the premise that gaming concepts can help to promote self-study, motivation, efficiency and effectiveness, and on-site training among astronauts.

The study has been performed in the context of a larger research program related to the development of a mission execution crew assistant, MECA[1]. The MECA research program focuses on crew assistance by means of an electronic partner to aid in mission operations. This also includes training and electronic learning systems. Within the MECA program, the impact on crew operations during long duration missions as well how to improve human machine interaction on these types of missions has been studied extensively[2,3,4]. An important output of the MECA program and its related projects is to establish a common requirements baseline for the cooperative and supportive interaction between man and machine during planetary missions.

II. Game Changer: Long Duration Missions

All aspects of crew member training will go through extensive evolution to incorporate changes to the training environment within future missions that foresee more than two years duration (e.g. Moon, Mars). Several changes to the training objectives, both in preparation but also on-mission in a dynamic and unpredictable environment are expected. Long duration missions are a game changer for training of astronauts. The assumption is that such missions will require a different type of training pre-mission as well as refreshing training or (re-)certification in-situ. This section will go into the details of changes for training in long duration missions. It implies large dynamics in mission goals, operational context, and therefore on the training related to that. This paper's hypothesis is that gamification, i.e. the use of gaming aspects, enhances motivation on these types of missions.

A. Changes to training preparation of a mission

What makes long duration missions different in terms of training preparation is that there will evidently be more time between any training pre-mission and the execution of a typical task on site (e.g. Moon, Mars). Training of the crew member according to today's standards will provide the required knowledge, skills and attitude to execute the complete set of tasks and experiments to be performed in a short mission. It is clear that if there is a longer time between knowledge and skill training and the real performance, essential information may be forgotten or more easily overlooked. Therefore during the mission and for the vast majority of his tasks the crew member needs to refresh or rehearse the training as performed pre-mission. It might also be such that the crew member will see training material only during mission travel for the first time.

Because of the nature of human memory, the whole training set-up may change, since in a long duration mission a lot more information for the crew members needs to be trained. For example, in today's missions to ISS the crew member will be on-board for typically not more than half a year. The difference becomes evident that when crew members are launched for their long duration mission, several experiments may still be under preparation and the related training material will be uplinked to the crew members during their travel. This provides a complete different training strategy compared to short mission training, since not all training can be completed or condensed prior to the long duration mission.

Another significant improvement needed for training during long duration missions is related to the aspects of skills training. Standard training of the crew member involves for the better part of the training time, actual training with hands-on experience. Crew members are trained with training models of actual hardware to be used in mission. Also, it involves training with simulator software packages that resemble the actual software on computers and laptops used in-flight. If the long duration mission training schedule of the crew member - as discussed above - will shift from pre-mission to in-mission training, it is required that new skills training methods are embedded. One can think of virtual reality simulator training methods up to the use of advanced motion/gesture controllers and augmented reality. Virtual reality with force feedback and 3D modeling will become part of future training capabilities. Today's motion sensing technology will become more and more embedded in serious gaming for professionals.

B. Changes to the mission

Training during long duration missions will require a new way of scheduling tasks. It is mandatory that crew members are trained pre-mission for safety critical aspects, such as handling the flight-system or landing systems, or even how to work in thermal controlled and pressurized spacesuits, and open hatches in a none-earthlike atmosphere. Nevertheless it can be expected that a vast majority of day-to-day tasks and work on experiments can and will be trained only during mission travel, or even just before experiment execution. The crew member automatic task scheduler will identify in short-term planning tools the tasks to be performed, and identify the preparation path with skill/training or even certification levels to be achieved before actually performing the experiment later in the mission.

Another difference with 'shorter' missions will be that some crew members may have advanced knowledge or skills on certain systems and in a collaborative training effort the experienced certified crew member will train the other crew members for certain tasks. Vice-versa for another topic the trainer/trainee roles may be reverse. In the MECA project, a prototype training tool has been developed and tested (a Collaborative Trainer, COLT), which supports such role switching for learning payload and first-aid operations[5].

Training material will sometimes become only available during the mission, for example the exact procedures or protocol of parameters will only be uplinked during the long duration mission. Then the crew member needs to re-certify or refresh the training courses. For this they will need access to the training database, and lesson material, or even may go as far as authoring new procedures for training and/or later execution of the experiment. In today's missions this is only very rarely experienced. A famous example is the replacement of the carbon-oxide filter in the Apollo-13 mission. In long duration missions these capabilities of training methods renewal will be crucial for mission success and scientific results.

C. Challenges to training Crew members in Long Duration missions

Given the above changes for training crew members on long duration mission it may be understandable that the human factor becomes even more important when the crew member is more left over to self-study, in-situ, without the class-room method & hands-on practice. Motivation enhancers for the trainees to do self-study and certify themselves in a long duration mission become mandatory in the future training tools they will use.

The long duration mission will have an impact on the cognitive and emotional state of the crew members. The cognitive state of the crew is impacted because they are not yet completely trained while already travelling, there is no tutor close-by and the communication delays become larger as the mission evolves. The crew member emotional state is impacted since they will feel left alone with the stand-alone training material and fellow trainees who encounter the same issues. A large demand on creativity and inventively resolving problems will be done on the crew member, and for that task they require the adequate supporting tools. Access to training databases, lessons material and certification paths will be more easily to accomplish when doing this in a challenging training environment. For this the so-called *serious gaming* methods for professionals may provide the answers, and for these tasks next generation gamification training tools are envisaged and outlined in the following sections of this paper.

III. Gamification: Gaming as a Motivator

Serious gaming or applying game aspects to serious problems has been around for some time. It has been used in the military market to train on all levels of command and operations. The benefits being that the use of computer systems and gaming technology can introduce situations that are normally difficult to summon. These systems rely heavily on the use of simulation. The term "serious gaming", however, does not necessarily imply the use of gaming technology, but actually more the use of gaming aspects, and tapping into the intrinsic drive that makes playing games fun and compelling.

The fact that people worldwide spend on average an increasing time playing computer games does mean that there is something compelling about them. The reasons why games are so compelling are the gaming aspects that can also be applied to 'serious' problems, rather than the trivial obstacles that are normally pursued in 'entertainment' games. Applying gaming aspects to solving a real world problem is the act of *gamification*, the result being serious games.

D. The fun of gaming

Why do we like to play games? This question has been tried and answered often in the past. In some cases stating that 'playing' has been around even before we had culture[6], being an almost primal urge. Most and foremost the reason we play games is because they are fun. But more importantly there is something compelling about games, that makes you want to come back for more. Either because you want to win, come back with a vengeance, or because maybe the game provides with a soothing experience that helps you relax. Underlying these emotional qualitative expressions, or getting hard fun while playing games, are the concepts of *flow* and *fiero*[7]:

- The notion of **flow** is the emotional state a person can achieve when performing a task so intensely that time seems to pass without noticing. These are usually moments of pure joy and happiness.
- The notion of **fiero** is an extreme positive emotion a person can feel by the rush one gets after achieving a goal that required a considerable effort, such as winning a marathon or solving a complex puzzle.

Both flow and fiero are important intrinsic drivers for continuous interaction with the game or system that causes these drivers. So a good game designer will design a game (rules, levels, quests, achievements, etc.) around game aspects that induce these drivers.

E. Gaming Aspects

Game developers worldwide try to make a game as compelling as possible, partly by providing a visually stimulating experience, but also by using gaming aspects to compel the gamer to play the game over and over, maximizing the length of the game session as much as possible. The following is a list of game aspects that we defined as instruments to enable this by actually tapping into the *flow* and *fiero* of the gaming experience:

- <u>Personification</u>: by representing the player into the game, the player feels he is part of the game, rather than just a player. A good example is introducing avatars, or profiles of the player. The player feels he should care about his avatar and will subsequently return to the game. As an instrument of flow, enabling this emotional tie will help increasing the time a user is exposed to the game. This effect becomes stronger when the user is able to invest and has done so in his character representation.
- <u>Quests or missions</u>: providing game experience in bite-sized chunks allows the game to give control to the player in how much and how long he wants to play. But also, it provides a clear overview of the game possibilities that are (currently) available to the player. These are great instruments for both flow and fiero. On the one hand, completing a quest in a manageable amount of time creates fiero soon enough to want more, thereby stimulating to play a string of quests, and thus flow.
- <u>Instant Rewarding</u>: providing rewards immediately after successful completion of a mission will induce fiero, provided that the reward is worthwhile and can be spent within the game for instance to unlock new and more exciting missions, or to boost character development.
- <u>Epic Scale</u>: achieving something grand, such as completing a difficult part of the game by cooperation between players, or by stringing together the completion of smaller missions will tap into both flow and fiero, because flow enables completing this 'grand' mission, and the reward in terms of fiero will be huge if completion is successful.
- <u>Social Comparison</u>: competition as a driving force to become the best. This is only achieved by trying to get better every time, either individually, or if collaborative training is allowed, as a team. By allowing players to compare their score to the score of others, we expect people to try and get the best, essentially enabling flow.

Of course these aspects are expected to be related to each other. For instance a good avatar system will only emotionally tie the player to the game if there are interesting missions to play, and if he feels that rewarding is balanced for proper character development. A proper balance of applying these aspects into a game is the key to success. To evaluate the effects of gaming aspects in our situation, we translated these gaming aspects into an actual prototype.

IV. Let's Play: A Portable Learning Application

An important goal of the APLA project was to take the high-level user requirements for long duration mission training support, and derive from them a generic software architecture suitable for basing actual support applications on. Figure 1 displays the generic architecture of the central APLA System and its decomposition into functional components. The architecture was designed in such a fashion that it could conceptually and technically interface with both current crew training systems (such as used at the European Astronaut Center (EAC)) and with crew operations on board a long duration mission platform such as e.g. the ISS.

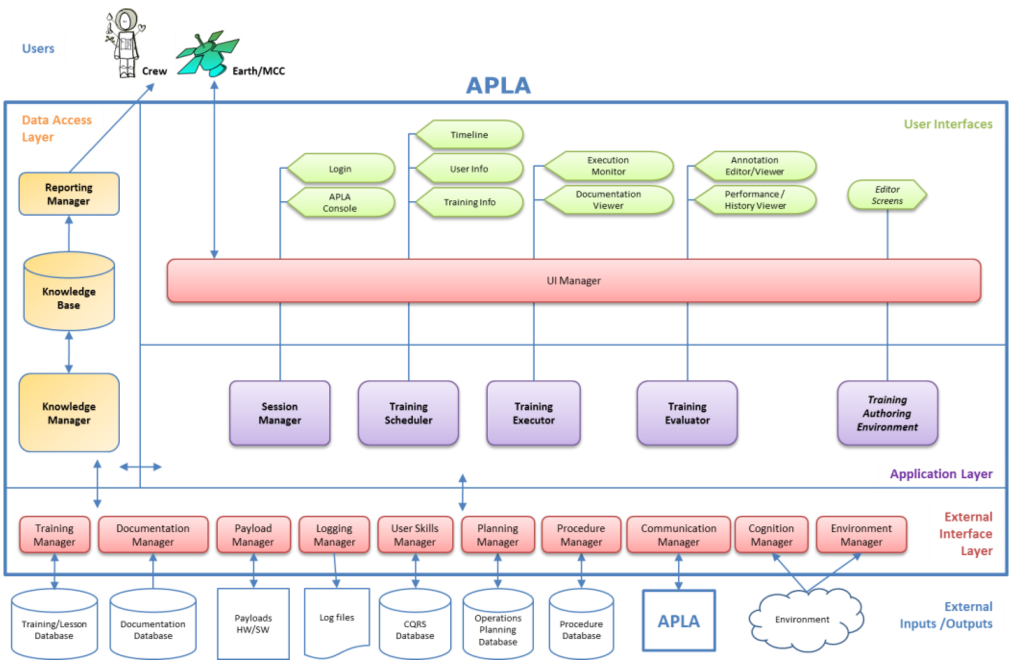

Figure 1. The APLA Architecture

F. Purpose of the APLA Demonstrator

Using the APLA Architecture as a starting point, we built an APLA demonstrator application for the purpose of illustrating and then evaluating our ideas on gamification as a vehicle for crew autonomy, motivation, and efficiency with respect to payload training. To keep the scope of the demonstrator manageable and within budget, and to allow us to thoroughly test a specific set of gamification ideas, we restricted the prototype (with respect to the full architecture and requirements baseline) in the following ways:

- The demonstrator is a prototype specifically intended for evaluation of ideas. Although self-contained and functional, it is not a full-fledged product that can be used outside the context of a 'walkthrough' test session.
- Support training for only a single payload (the Cardiopres physiology module).
- All actual lessons are implemented by external 'black box' applications, or by stubs containing dummy content. APLA is about the *presentation* of the training, not the training itself.
- Implement and focus the evaluation on the "six core principles" of gamification (discussed below).
- No authoring tools for either lessons or lesson meta-data were created.
- APLA to be integrated as a module into the research MECA Mission Execution Crew Assistant framework (rather than in an actual ISS or EAC environment).

G. Implemented gaming aspects

In the APLA demonstrator we have implemented a large number of requirements from the APLA requirements baseline, in order to be able to study the consequences of providing personal, computer-aided training to the crew of long duration manned missions. We particularly focused our implementation (and subsequent evaluation) on the deployment of gamification principles, as discussed in Section IV. We implemented six 'core' gamification functions in the demonstrator, because they support our primary goals of motivation, autonomy and efficiency, and because they are very representative of the concepts of 'fiero' and 'flow', as explained in the previous Section. The six core APLA functions are:

- *Learning space*

The first central APLA 'support pillar' is a transparent personal learning space that provides visualization and situational awareness to the user with respect to their current position in the 'training space'. Its purpose is to give an overview of active, completed and possible future learning activities; to display the trainee's current certifications and achievements, and to show the trainee's skill levels in various relevant categories. Learning activities are represented in the demonstrator mainly as individual, short lessons (the APLA form of 'quests'). Certifications are formal content-based qualifications (such as e.g. an operator-level certification for a specific payload), and can be the result of successfully passed exams or sequences of lessons being completed. Achievements are similar, but are pure gaming elements based around playful goals such as e.g. a trainee completing their hundredth lesson, or spending a certain amount of time in APLA. Skill categories are the key towards unlocking lessons and trainee progress: every lesson requires certain skill levels before it can be attempted, and every successfully completed lesson will reward the trainee with additional skill points.

- *(Procedural) training guidance*

Training guidance is the second central APLA support pillar. APLA supports the trainee in selecting, executing, and evaluating lessons. Every lesson in the system can be executed from within the APLA demonstrator (by means of starting an external application that actually runs the lesson). Currently supported in the demonstrator are video lecture lessons, viewing text or PDF-based syllabi, operational procedural training, and interactive 'exam' lessons. The plug-in architecture is open, however, and other types of lessons can easily be added (e.g. a simulator application). Once the lesson is completed, APLA resumes control, and assists the user in evaluation, showing the results from the lesson, such as an achieved certification and increased skill levels.

- *Skill graph*

The skill graph is an element that ties the training guidance and the learning space together: it is an example of how a support application such as APLA does not just run a lesson, or show a user their status, but can also help them decide which lesson to choose next, i.e. given them the autonomy to plan their educational path through the training space. The skill graph does this by giving a two-dimensional graph-like representation of the dependencies between a set of available lessons (see Figure 2). It visualizes which lesson the user has already completed, and shows the available paths to certain goals (e.g. certification). Once an interesting lesson has been identified, the user can find detailed information about the lesson in the hierarchical training catalog (based on the one currently in use at the European Astronaut Center (EAC)). The skill graph also shows at a glance the skill requirements and rewards associated with each lesson, and whether or not that lesson is currently available to the trainee.

- *Notifications*

The notification area of APLA is similar in concept to the notification areas found in current Smartphones and mobile devices (both for games and in general). The purpose is to dynamically display (and allow the user to manage) messages from the system as they come in, thus keeping the trainee in the loop and informed about what is going on at all times. Notifications can be purely informational (e.g. notifying the trainee they have achieved a goal, or that an event has completed), but can also be warnings or other alerts (e.g. that a certification is about to, or already has expired for that user). Thus, notifications form another means by which APLA can provide situational awareness and support users in choosing the best course of action, training-wise.

- *Annotations*

Annotations are a generic mechanism by which the user can actually input information into the APLA system, rather than just consume it read-only. In the simplest form, annotations are like post-it notes: user-generated content that can be attached to almost any object (such as e.g. a lesson or a procedure step) within the APLA system. Annotations are persistent and can be viewed by other users of the system (depending on privacy settings). Annotations can be private or public, generic or specific. They can contain text, but also multi-media content (pictures, attachments, voice recordings, etc.). They can be free-form or highly structured (e.g. bug reports submission forms), and can be global or intended for a specific group of recipients. They form a simple means for the users of APLA to asynchronously communicate with training authors, with ground control, with each other, and even with their future selves. In this way, a body of knowledge based on the actual experience with the training system will be built up.

- *Social comparison*

Finally, one of the hypotheses we wanted to investigate was that a light, healthy form of competition can be an excellent means of providing motivation for a crew member to continue and excel in their training activities. To be able to test this, APLA contains a number of social comparison elements, chief of which is the Leaderboards tab, where each user can see how all users are ranked in terms of their skill levels for the various skill categories. Another example is the fact that the entire user catalog is initially visible to everyone, so it also possible to see in detail how far other users have progressed in their training, which lessons they have executed, the position on their skill graphs, etc. Although not implemented in the current demonstrator, it would also be possible to integrate social comparison into some of the other gamification mechanism, such as for example notifying somebody when they reach (or lose) the top position in a skill category, or showing the position of multiple users within the same skill graph.

The APLA demonstrator was implemented as a rich client in the Java programming language, using mainly open source protocols and standard libraries and GUI elements.

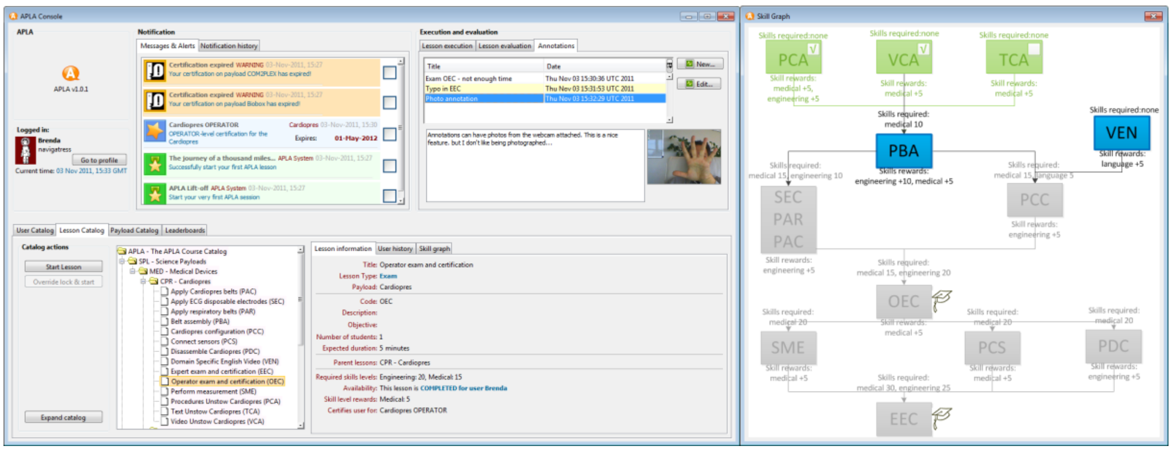

Figure 2. (a) The APLA Demonstrator console windows; (b) A skill graph.

V. The Score: Results of the Evaluation

This section first briefly describes the setup of the evaluation and then the results of the evaluation.

H. Structured walkthrough

The six core functions that were implemented were justified in the evaluation by corresponding claims. Claims are concrete and testable upsides and downsides of the core function and referred to with measures such as: training effectiveness, training efficiency, satisfaction etc. For an impression of the evaluation, see Figure 3. The evaluation process was as follows:

- Short introduction; to explain the objectives and scope.
- Questions; concerning the expectations of the participants on the training support.
- User exploration; the participant is given control over the Demonstrator, and is asked to think aloud while ‘using’ the demonstrator.
- Structured walkthrough; based on a scenario the test leader walked through the Demonstrator with the participant. At times when a core function was used, the test leader asked the participant questions related to the claims.
- End questionnaire with multiple choice as well as open questions on the activities and observations during the walkthrough
- Interview with the participants to observe the general reception of the application.

Figure 3: participants filling in the questionnaire behind the demonstrator, on the left submarine crew and on the right training experts from EAC

The evaluation took about 1½ hours. During the evaluation, a specialist was seated next to the participant, observed his actions and, if necessary, asked questions for clarification. The experiment was performed by fifteen participants who walked through the demonstrator with the test leader. The participants were from a variety of relevant backgrounds; ranging from engineers from ESA (space mission experience), submarine crew (experience with long duration missions in isolation), and training scientists, to trainers from the EAC.

I. Results

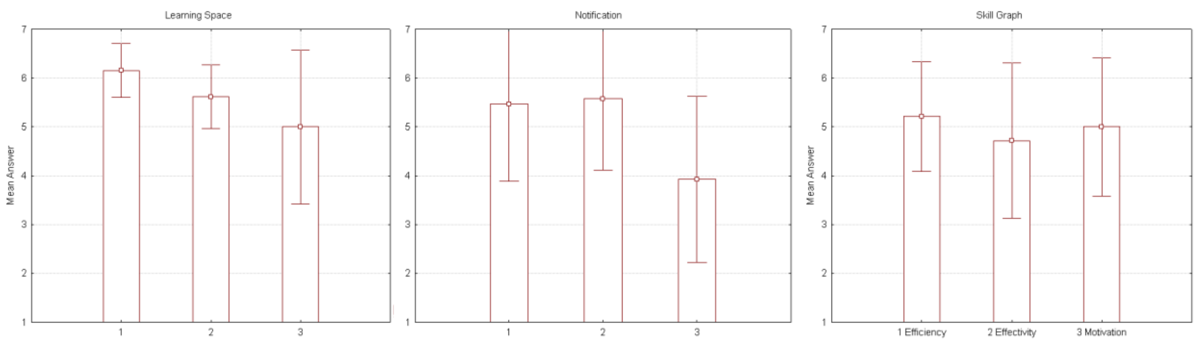

Figure 4. a) mean answer and standard deviations to questions concerning claims for learning space core function b) notification core function and c) skill graph core function.

Learning space. The mean answers show that participants are positive that APLA supports the user in his awareness about his training progress (see Figure 4a; question 1). The mean answers show that the participants are positive that APLA helps to reach certification more efficiently (question 2). The mean answers show that the participants are a bit more than neutral on the motivational aspect of APLA (question 3), the variance in the answers are large.

Procedural training guidance, was evaluated a bit more than positive on learning skill (transfer to performance in 'real' operational performance), but with a big variance in the answers. Feedback was given on this by participants that they would like a demo with a full lesson.

Notifications. The participants felt more aware about the schedule for certification with the notifications (see Figure 4b, question 1). They trusted APLA to schedule the re-certification (question 2). The notifications themselves were too interruptive (question 3).

Annotations, were rated low on the claims referring to this core function. The function, however, was liked by participants and was labeled as important in the explanation of their answers and discussion, but not as it is now. Good suggestions were given how to improve this function: annotations should be able to set on public, private and feedback to ground. It should be possible to link annotations to a lesson and annotations can also be used as Q&A with Ground or crew members.

Social comparison. The implementation of the social comparison should be reconsidered, because as it is, it may have a considerable negative effect on (some) users. It probably should show more the relative position in crew competencies than provide a competitive game-like ranking.

Skill graph. The results of the skill graph all show big variances, see Figure 4c. Remarks showed that the participants thought that the skill graph would not add to the effectiveness (the courseware would) or the motivation. Furthermore, this function should be more interactive to be able to give more feedback on this.

Several users found the demonstrator too kiddy like. This was a result of the avatars and colors, but also of the gamification aspects like the achievements. Some participants found the achievements motivating (participants with background knowledge of training, younger representative end-users), others unnecessary or even infantile (some representative end-users). An aspect that influences the opinion on features like this can be different for users depending on age (whether they have grown up with game-like features as achievements) or background. This is something that needs to be evaluated with real end-users. Another influence is that the content was not a focus of this evaluation. Would more serious content have been available, this aspect might have been evaluated more positively. A recommendation is that the next demonstrator should have a more extensive and realistic content to train participants.

VI. Lessons Learned

During our study we have argued that to keep crew well-prepared on long duration missions for operational tasks in a dynamic environment the need for training is very important. However, emotional aspects of the long duration of the missions include a decline in motivation and a loss of interest in self-study. Our initial results indicate that with the introduction of gaming aspects these may be overcome. Especially the aspect of giving control to the trainee is perceived as very positive, as well as the overview on available lessons that the skill tree and the transparent learning space provides. Currently the use of gaming aspects as we have demonstrated is not yet used in current astronaut training, however it is a welcome addition to the training curriculum. More research should be done to further study the applicability of serious gaming to training of astronauts. We've only barely scratched the surface.

Acknowledgments

This research took place in the APLA project (contract 4000102351) funded under the General Support Technology Programme (GSTP-4). We would like to thank EAC for their input during the project and as participants during the evaluation. Other parties that participated in the evaluation and we would like to extend our thanks to are: Submarine Service of the Royal Netherlands Navy, ESA-ESTEC and TNO.

References

[1] Neerincx, M.A. Bos, A., Olmedo-Soler, A. Brauer, U. Breebaart, L., Smets, N., Lindenberg, J., Grant, T., Wolff, M. (2008). The Mission Execution Crew Assistant: Improving Human-Machine Team Resilience for Long Duration Missions. Proceedings of the 59th International Astronautical Congress (IAC2008), 12 pages. Paris, France: IAF. DVD: ISSN 1995-6258.

[2] Diggelen, J. van, and Neerincx, M.A. (2010). Electronic partners that diagnose, guide and mediate space crew's social, cognitive and affective processes. In: Spink et al. (Eds.), *Proceedings of Measuring Behaviour 2010*. p. 73-76. Wageningen, The Netherlands: Noldus Information Technology b.v.

[3] Neerincx, M.A. (2011). Situated Cognitive Engineering for Crew Support in Space. *Personal and Ubiquitous Computing*. Volume 15, Issue 5, Page 445-456.

[4] Baker, C., Naikar, N. and Neerincx, M.A. (2008). Engineering planetary exploration systems: integrating novel technologies and the human element using work domain analysis. Proceedings of the 59th International Astronautical Congress (IAC2008), 15 pages. Paris, France: IAF. DVD: ISSN 1995-6258.

[5] Smets, N.J.J.M., Neerincx, M.A., Cohen, I. and Diggelen, J. (2012). *Improving crew support methods in human-machine teams for long duration missions.* IAC 2012, Naples.

[6] Huizinga J., *Homo Ludens*, (1971), Beacon Press

[7] McGonigal. J, *Reality Is Broken: Why Games Make Us Better and How They Can Change The World*, (2011), Penguin Press