ALF - a Framework for Evaluating Accelerated Learning in Industry

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Abstract

Games have long been considered as a means to support effective learning, motivate learners and accelerate their learning. Several successful studies using game-based learning are reported in the literature. However, there appears to be a research gap on systematically evaluating accelerated learning in game environments. The main research question we address in this paper is how can we evaluate accelerated learning in game-based learning environments? The main contribution of this paper will be a framework for evaluating accelerated learning in games (ALF). We will illustrate the use of this framework by describing studies conducted in the Norwegian industrial project ALTT (Accelerate Learning Through Technology), aimed at capacity building in the aluminium industry, where we have co-designed a game for accelerating learning about the electrolysis process for extracting aluminium and heat balance in the aluminium production cells.

Keywords: *Accelerated Learning, Game-based learning, Cognitive Skills, Workplace Learning; Evaluation;*

1 Introduction

Many industries are experiencing significant changes due to digitisation of the workplace. As such, employees are faced with new demands for cognitive skills and challenged to acquire them rapidly. Many organisations have recognised this need and are looking at new means of engaging employees and using novel and digital solutions for accelerating learning in the workplace. Successful engagement of employees in their work are seen in organisations that invest in the employee experience [1].

The use of games, as a means to support effective learning, motivate learners and accelerate their learning; e.g. [2-4], has gained increased interest by several industries in recent years. Although there is growing evidence in the literature of successful studies using Game-Based Learning (GBL), there remains a research gap on systematically evaluating accelerated learning with GBL in workplaces. While GBL claims it can accelerate learning, there are no frameworks that explicitly address this. Furthermore, the transferability of what is learned to the real world is often neglected in the evaluations. This paper presents a framework for evaluating accelerated learning in games, ALF. An earlier version of this paper was presented at the GALA 2018 conference [5].

Our main research question is how can we evaluate accelerated learning in game-based learning environments at the workplace? We draw inspiration from the work done by the Serious Game community (e.g. [2, 6-8]) and the research in adult learning (e.g. [9, 10]). We illustrate the use of this framework by describing studies conducted in the Norwegian industrial project ALTT (Accelerate Learning Through Technology), aimed at capacity building in the aluminium industry, where we have co-designed a game for accelerating learning in the process industry – the ALTT Heat Balance game. The project partners are the Norwegian aluminium producer Hydro, Attensi who develops gamified training solutions, Cybernetica who develops simulation models for dynamic process control and SINTEF as the research partner and game and learning designer.

Using the seven principles of accelerated learning from Meier [10], we broaden the perspectives of learning traditionally adopted in serious games studies, where learning is considered beyond the knowledge retained after an intervention and consider the transformation of the learner's attitudes, motivation, confidence and reflection. We have developed the Accelerated Learning Framework (ALF), which has been used to design the evaluation of accelerated learning. The paper describes ALF and discusses the results of evaluations and the potential to support accelerated learning in games.

The rest of this paper is organised as follows: Section 2 provides a background on accelerated learning; Section 3 presents ALF and describes the ideas for designing and evaluating accelerated learning using ALF; Section 4 describes the ALTT Heat Balance game; Section 5 describes the evaluation method for accelerated learning using ALF; Section 6 describes the results of evaluating learning; Section 7 discusses the results from evaluating accelerated learning using the ALTT Heat Balance game and finally Section 8 concludes the paper.

2 Accelerated Learning

In the process industry, as in any other industry, the amount of time spent by personnel in competence development, learning or conducting training programs correspond to productivity loss and is usually associated to a cost rather than an investment. There is a need for effective learning support, in particular, for learning support that accelerates the learning process and faster transfer of the competence gained to enhanced skills in the workplace. Consequently, there is a strong desire to reduce the time to competence [11].

Accelerated Learning has been defined as "faster attainment of skill and knowledge, and an increase in on-the-job performance with better retention of learning" [9]. Other definitions also focus on the time factor; e.g. "any learning system that attempts to optimise time spent learning versus content learned" [12]. The depletion of knowledge over time, or retention, is seen as an important factor [9]. Andrews' and Fitzgerald's [9] definition addresses the needs of the industry to gain skills and knowledge that lead to a better performance at work. This implicitly sets some criteria on the types of skills and knowledge that are most relevant to be attained in order to lead to a better performance in the workplace in a shorter time.

Within the context of adult learning and training, accelerated learning takes a multidimensional approach and places the learner in the centre [13]. The origins of a "whole-body, whole-mind, whole-person experience" learning process was proposed by Meier [10]. This approach makes the use of multisensory learning environments, brings the ideas from Howard Gardner's multiple intelligences and makes use of both the right and left brain of a person. Meier's work has been used by several authors as the seven guiding principles of accelerated learning [14]:

(i) learning involves the whole mind and body, with all the senses, receptors and emotions that go with it;
(ii) learning is creation, not consumption and knowledge is not absorbed, but created. This assumes learning as the creation of new meaning and understanding and assimilating it into the work we do.
(iii) collaboration aids learning; learning is better within a social context and we often learn in collaboration with peers rather than in isolation.
(iv) learning takes place on many levels simultaneously; learning is not a matter of one thing at a time, but many things at once.
(v) learning comes from doing the work itself (with feedback) and real concrete situations are often better than hypothetical and abstract concepts.

(vi) positive emotions greatly improve learning; learning that is joyful, relaxed and engaging is more effective.

(vii) the image brain absorbs information instantly and automatically; images are easier to retain than verbal abstractions.

Several accelerated learning methods have been discussed in the literature and the evaluation of the learning outcome is important to determine the efficiency of the learning method. A set of features and characteristics proposed to evaluate the methods are based on three features: planning, application and deep understanding [4]. Planning involves engaging the learners when introducing new material and illustrating the use of the knowledge. Application involves the learner demonstrating the use of the knowledge and the consequences of applying the knowledge. Deep understanding involves engaging the learner on reflection upon her own learning and self-assessment of the application of the knowledge.

2.1 Accelerated Learning in Games

Game-based learning often claims accelerated learning, e.g. [4], for a number of reasons. Some of the common arguments for the claims are that game-based learning environments can support experiential learning [15] and provide a safe and cost effective virtual learning environment for learners to practice applying their skills. Game-based learning environments provide the opportunity for learning by doing in a virtual environment, simulating situated learning [16], which can represent the relevant learning context [17], all of which are important aspects for learning. In addition, games deliver on a number of the guiding principles of accelerated learning described earlier, such as involving the whole body and mind and learning on many levels. Games often support deep understanding and self-assessment by providing capabilities to support reflection within the game and external to the game [18].

Positive emotions, emotional engagement and immersion are experienced by learners. Good game design can often result in deep learning and high levels of personal satisfaction. Affective learning relates to the learner’s interests, attitudes, and motivation [19-21]. Issues relating a learner's emotions and learning are not new and games and other technologies to support learning help focus the attention on the affective domain as well as the cognitive domain, identified by the Bloom's taxonomy [21, 22].

Good game design is also guided by Csíkszentmihály's Flow theory, which describes an optimal psychological state that people experience when engaged in an activity that is both appropriately challenging to one’s skill level, often resulting in immersion and concentrated focus on a task [23]. Gee uses the term "pleasantly frustrating" to describe the play to be challenging without being unmanageable for the learners [24].

Games are good examples of learning support that falls into the constructivism approach to learning. Vygotsky's Zone of Proximal Development (ZPD) identifies what a learner can do with help and what they can't do [25]. Thus, learning content that has the right level of difficulty will reduce learner's anxiety and boredom and with the right scaffolding or help, this is where learning can be most effective [26, 27]. ZPD can be a state of "ready to learn" where flow and the level of challenge of the instructions is appropriate to the learner [27].

2.2 Earlier Frameworks

Frameworks exist for the selection of an appropriate game for learning, e.g. [2], to help educators in choosing the right pedagogic approach and a game. The ideas from this framework by de Freitas et al. have later been developed as a framework for evaluating learning as immersive experiences [28]. This framework identified four dimensions: model or profile of the learner, the pedagogical aspects such as current knowledge of the learner, the context and the representation of it, such as the interactive nature. Mayor et al. proposed a comprehensive conceptual framework to support the design, data gathering and evaluation of serious games [7]. Mayor et al.'s framework takes into account the pre- and post-game conditions such as the learners' knowledge and attitudes; mediating variables such as learning styles and the context of learning. Furthermore, it provides guidelines for ensuring the quality of the intervention and data gathering for the evaluation. While these frameworks provide ideas for the evaluation of learning, they lack explicit support for the evaluation of accelerated learning using games, in particular, in adult learning at the workplace.

Frameworks to support effective game and learning design have been reported in the literature. The LM-GM framework by Arnab et al. [2, 6-8], which maps the relationships between pedagogy and game mechanics (i.e. learning mechanics to game mechanics), provides a good support for designing effective serious games and for analysing serious games. Similarly, the Activity Theory-based Model of Serious Games (ATMSG) by Carvalho et al. [29] also provides support for effective serious games design and for analysing serious games. Both these frameworks were designed primarily for game designers and researchers. While these frameworks could support effective serious games design, they do not explicitly address the design of games for accelerating learning or evaluating accelerated learning.

One of the main differences between our work and other frameworks for evaluating learning and for the effective design of serious games is that our work has been conducted within an industrial context, with the end users. In addition to designers and researchers, the main users of our framework, ALF, will include users from the industry and people who conduct training programmes in industry. Thus, our proposed framework attempted to bridge the theoretical aspects with the needs of the industry and the end users.

3 ALF – Framework for Evaluating Accelerated Learning in Games

Three perspectives can be identified as central for supporting accelerated learning; the cognitive and affective domains and the context of learning; see **Error! Reference source not found.**. The cognitive perspective addresses deep understanding of concepts and high-order learning skills such as reflection both on the learning process and during the learning process. It includes effective learning design, such as Vygotsky's ZPD [25], where the level of difficulty of the learning content must not be too difficult or too easy for the learner; rather adjusted to provide the right amount of challenge to the learner while being able to attain the new knowledge. It also focuses on ensuring appropriate cognitive load to reduce the load on the working memory to support retention of knowledge [30]. Indeed, aspects such as preferred learning style will play a role in supporting the learning process.

Affective learning relates to the learner's emotions, interests, attitudes, engagement and motivations [19, 20]. Engagement is often associated with the degree of attention, interest and curiosity that a learner shows when they are learning [26]. Bridging ideas from effective learning design and Csíkszentmihály's Flow theory [23] are important in designing for accelerating learning, to ensure that learners are engaged in an activity that is appropriately challenging to one's skill level. Gee uses the term "pleasantly frustrating" to describe the play to be challenging without being unmanageable for the learners [24]. Bringing together Vygotsky's ZPD, Flow theory and Gee's "pleasantly frustrating" concept can lead to affective learning, where the learner could experience the feeling of mastering while enjoying the learning and anxiety and negative emotions could be avoided.

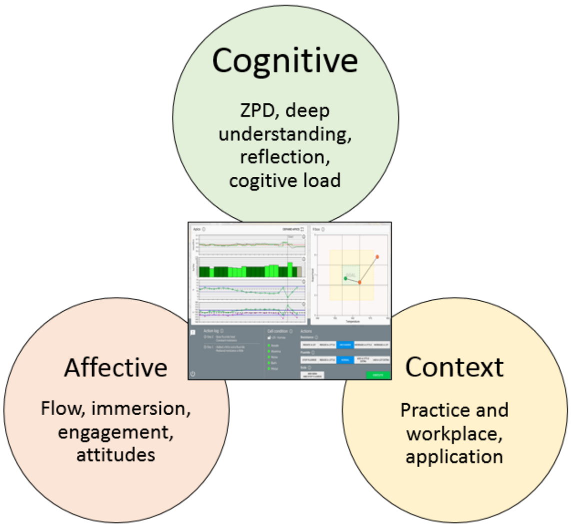


Figure 1. *Main concepts in Evaluation Framework for Accelerated Learning (ALF)*

Contextualising the learning so that the learners could practice in a relevant and realistic virtual environment supports accelerated learning and increases retention. Building on tacit knowledge [31] and the prior knowledge of the learner [26] have been identified as important for learning. A realistic game environment that the players could relate to are thus important not only for supporting accelerated learning, but also to ensure the usefulness of the new knowledge that is attained. The potential to easily transfer what they have learnt to their work situations is important [32].

3.1 Synergies among Perspectives

The synergies among these three perspectives, Cognitive and Affective perspectives and Context, are important for accelerating learning. These ideas and concepts are consolidated in ALF, which is illustrated in **Error! Reference source not found.**.

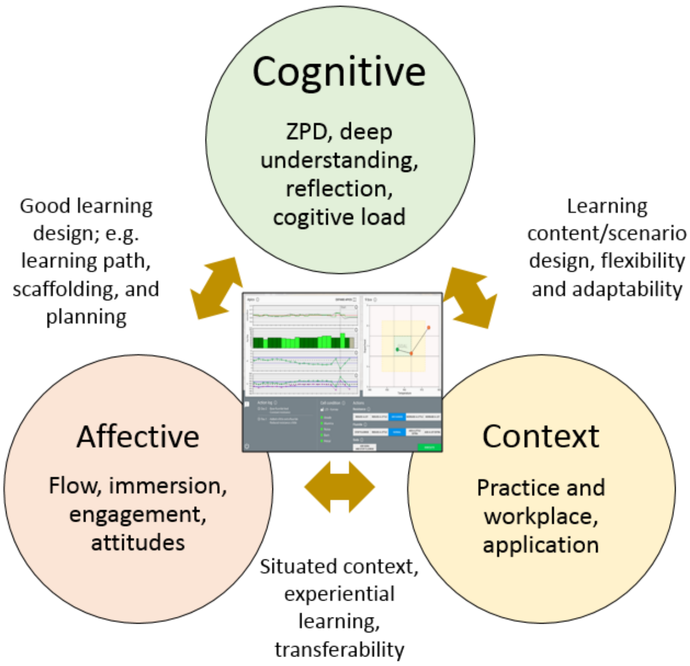


Figure 2. *Synergies across the main concepts in ALF [5]*

The cognitive-affective perspectives are relevant for determining good learning design, planning the learning progression and ensuring the right level of help or designing scaffolding. As discussed earlier, the appropriate level of difficulty and challenge is essential for effective learning and deep understanding. The progression of the learning path through the game scenarios and appropriate feedback on the learner's performance can be designed by considering these two perspectives.

The synergy between the affective domain and the learning context can support experiential learning and transferability of the learning to the work context. The learning context provides a realistic virtual environment where the learner could be actively engaged in the learning activity and receive timely and appropriate feedback.

Finally, the synergy between the learning context and the cognitive domain can support the design of the appropriate learning content and activities to ensure deep understanding. The choice of the learning contents and the choices and possibilities available to the player to adapt to their preferred learning style can play an important role in providing the appropriate cognitive support. For example, some may prefer abstract graphics while others may prefer a higher degree of precision; or some may prefer graphs to other forms of visualisations of data.

These perspectives have similarities to the framework for evaluating learning as immersive experiences by de Freitas et al. [28]. By considering the synergy between two perspectives, we address all the dimensions identified by de Freitas et al. such as pedagogy and the learner profile and model; e.g. the learner profile will be relevant information in determining the appropriate content: synergy between the cognitive and context perspectives.

3.2 Evaluation Design for Accelerated Learning

In this sub-section of the paper, we will describe how ALF, illustrated in **Error! Reference source not found.**, and the three perspectives described in the previous sections can be elaborated to apply the ideas in the evaluation of accelerated learning. We have categorised the criteria and the guiding principles for accelerated learning from the literature into the three perspectives identified in ALF. The criteria relevant for evaluating accelerated learning and types of activities that could be done in the evaluations are described in **Error! Reference source not found.**. Some of the criteria address more than one of the perspectives; e.g. reflection is a cognitive support while it can reinforce the learning context. Similarly, feedback applies to both the cognitive and affective domains, e.g. a hint or clue is in the cognitive domain while a reward (as a feedback) is in the affective domain. These concepts and ideas have been used to design the pre- and post-intervention questionnaires.

Table 1. *ALF Criteria for evaluating Accelerated Learning in games*

Perspectives	Criteria	Evaluation Activities
Cognitive	Reflection and reflective practice [33]	In-game and post-intervention questionnaire, through interviews and discussions.
	Preferred learning style [34]	Pre- and post-intervention questionnaire: self-reported attitudes. In-game: active learner through game logs, learner contributions.
	Creation, not consumption [10]	In-game: active learner through game logs, learner contributions.
Affective	Emotional engagement [19, 20]	In-game: through game logs. Post-intervention questionnaire: self-reported.

	Attitudes and motivation [19, 35]	Pre- and post-intervention questionnaire: self-reported.
	Feedback [10]	In-game: through game logs to see if the learner's play is affected by the feedback.
Context	Learning by doing, and in context [15, 16, 36]	In-game: through game logs. Post-intervention questionnaire: self-reported.
	Transferability [9]	Post-intervention questionnaire: self-reported.
	Collaborative and social learning [10]	In-game: through game logs. Post-intervention questionnaire: self-reported.
	Images, visuals [10]	In-game: through game logs. Post-intervention questionnaire: self-reported.

4 Heat Balance Simulation Game

The context for the ALTT Heat Balance game was the aluminium production cells and the heat balance in the electrolysis process. One of the cognitive challenges in this context was the fact that in real life, the electrolysis process could take days as the chemical processes in the aluminium production cells are slow. The domain required the understanding of the dependencies among the parameters temperature, acidity, superheat and the liquidus temperature, and hence the learning goals were based on these. Since the electrolysis process is a dynamic process, a key design decision was to implement a dynamic process model of the cell that could simulate future states of the cell. The actions in the game can be translated as parameter values for the dynamic process model. The gameplay is based on rounds, each corresponding to a 24-hour time period, and the game environment calls the associated dynamic process model to obtain the new status of the model, based on the actions taken by the player.

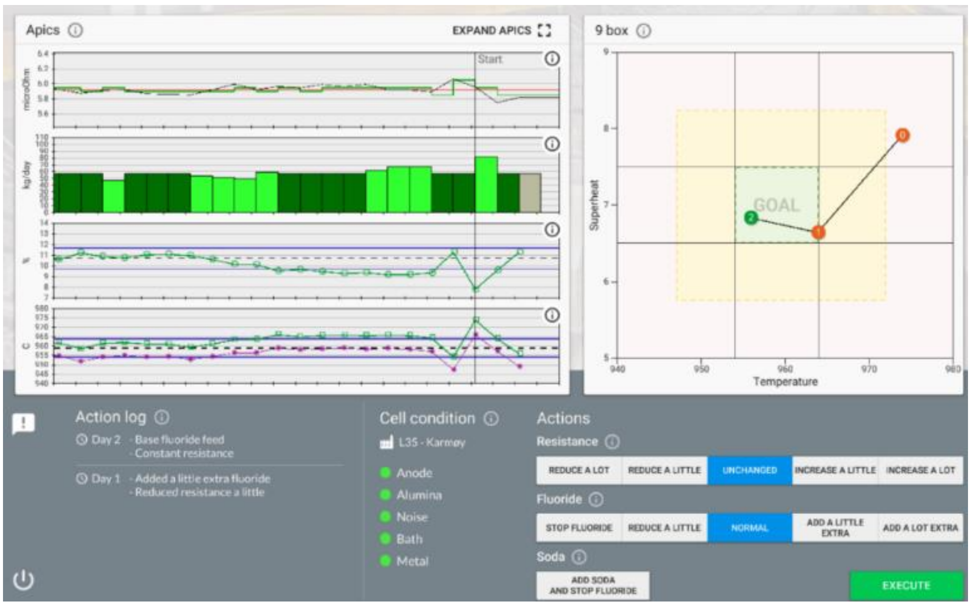


Figure 3. *Screenshot of a game session of the ALTT Heat Balance game*

As illustrated in **Error! Reference source not found.**, the game is designed around a 9-cell matrix, with axes showing the bath temperature and the superheat – the 9-box model. This is the essence of the conceptual model that captures the interdependencies of the aforementioned parameters associated to the electrolysis process. The player starts by selecting a game scenario, which has a learning goal and subgoals. At the start of the game scenario, the current state of a production cell is shown as a dot position in the 9-box model and a corresponding set of graphs (e.g. the dot in the top right cell of the 9-box model in Screenshot of a game session of the ALTT Heat Balance game. The start state, in this case, is an unstable cell or a deviation state. The goal of the player is to stabilise the cell by obtaining the appropriate values for temperature and superheat, which is bringing the new state of the cell to the values indicated by the centre cell in the 9-box model and maintaining those values for three consecutive rounds. The winning state is maintaining a stable cell for three consecutive rounds. For example, in the screenshot in **Error! Reference source not found.**, the player has managed to bring a cell to a stable state in two rounds and has the possibility to win the game in two more rounds if she could maintain the new states within the centre cell. For each game scenario, a player is allowed twenty rounds. If the player does not manage to win in twenty rounds or drives the cell outside of 9-cell model (the game board), the player loses that game.

The other main Graphical User Interface (GUI) component is the cell's historical information, which is shown as a set of graphs, which include information on resistance, fluoride additions, acidity and bath temperature. The game is played by selecting one or more actions that will be taken on a cell, shown bottom right of the GUI. The actions available in the game are changing the resistance and the amount of fluoride (acidity) in the cell, wait without taking any action or add soda to the cell. Once an action is taken, the graphs and the 9-box model are updated with the new state of the cell, calculated using the dynamic process model.

Hints and feedback are provided during the game play; e.g. if the player is one or two rounds from winning the game (e.g. as shown in **Error! Reference source not found.**), feedback is given in the form of an encouragement. The scoring is based on two aspects: (i) the difference between the optimum number of rounds for winning the game and number of rounds used by the player to win, and (ii) how well the player anticipated the consequences of their actions through the game play, as shown in **Error! Reference source not found.**.

The game was co-designed with the operators and domain experts to ensure its relevance for the workplace and to understand the context of learning as well as to engage the end users from the beginning. Paying particular attention to accelerating the learning process, inspirations from Cognitive Task Analysis (CTA) methods, (e.g. [37]), were used to understand the typical problems faced during a working day, operators' cognitive challenges and the cues and hints that help them understand their tasks and the domain knowledge.

Learning path and progression and functionality to support reflection and timely and appropriate feedback were explicitly considered during the design process; e.g. see [38]. Functionality to support a reflective practice was implemented to ensure that the operators reflected on the current status by looking at the history shown in the graphs and looked ahead by anticipating the consequences of their actions before deciding which action to take. Three questions were presented to the players after each action in the game, to stimulate them to reflect on the current status and to anticipate the consequences of their actions; see top part of **Error! Reference source not found.**. Feedback on the reflection is provided immediately by showing the player's anticipated or assumed consequences and the actual consequences (simulated using the dynamic process model); see bottom part of **Error! Reference source not found.**.

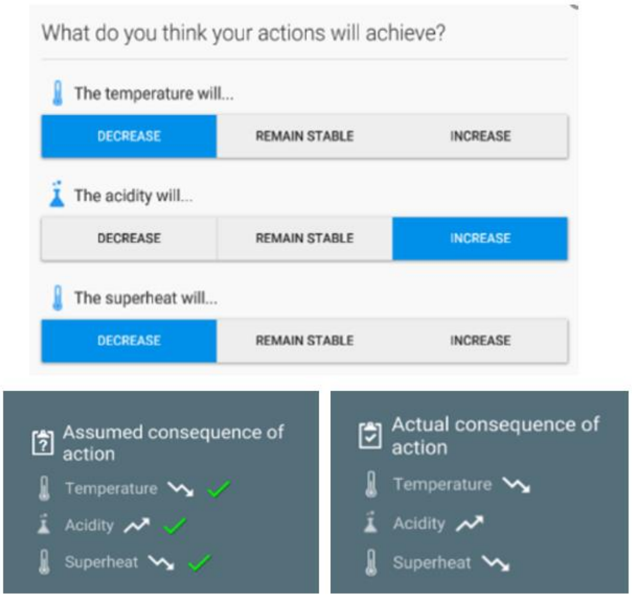


Figure 4. *Support for in-game critical reflection and feedback in the ALTT Heat Balance Game*

5 Evaluation Method

Several formative and summative evaluation studies were conducted over a period of one and a half years. Formative evaluations were conducted during the iterative design stages and focused explicitly on specific elements such as getting the dynamic process model correct, the game mechanics and the user interface. Iterative developments of the game design, the dynamic process model and the user interface continued during the formative evaluations. The summative evaluations were conducted after the digital game was completed and focused on the learning related aspects. The main aim of the studies was to evaluate the potential to support learning or knowledge gain. However, the evaluation method and material, particularly the pre- and post-intervention questionnaires, were designed with particular attention to evaluate if and how the game could support acceleration of learning, based on the ALF framework.

Several methods were used during the formative evaluations. Participants, who were experienced and novice operators, were asked to play in pairs and talk aloud, or play individually. The play sessions lasted between 30-45 minutes. The project team observed the play sessions, which were followed by a focus group discussion or individual interviews. The focus of the formative evaluations varied; in the beginning the focus was on determining the appropriate game concepts and game mechanics and the user interface. Ensuring the correctness and preciseness of the dynamic process model was important to ensure a realistic game and this was the main focus when the game was evaluated by expert operators.

The summative evaluation method was based on pre- and post-intervention knowledge tests, combined with self-reporting through pre- and post-intervention questionnaires and in-game session log data [7]; as shown in **Error! Reference source not found.**. The pre and post knowledge questionnaires were designed to evaluate the knowledge gain by playing the game. The pre-intervention background and post-intervention questionnaires included the three perspectives of ALF, such as attitudes, perceptions, usefulness and usability, transferability and confidence. Specific questions were included to evaluate if the game has the potential to support accelerated learning.

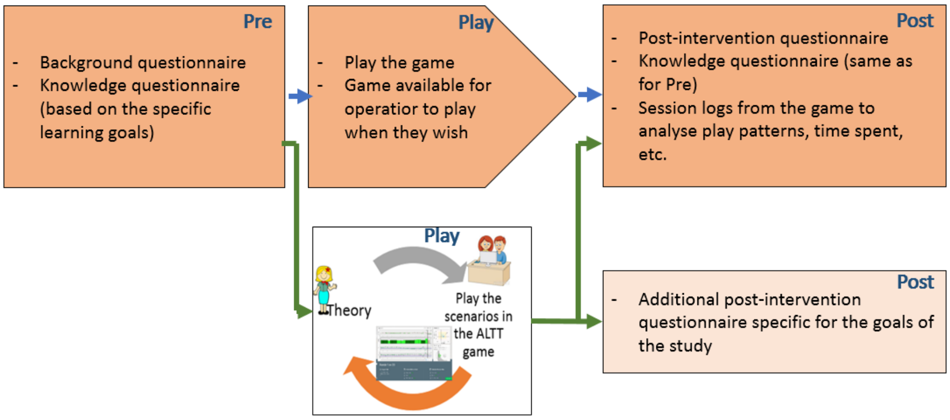


Figure 5. *Summative evaluation method*

For two of the evaluations, the participants were given a period of two weeks to play the game in their own time. For the other two evaluations, the game was a part of a theory course where the instructor introduced concepts (theory or a scenario from the game) and then asked participants to play the specific game scenario relevant to the theory. This is shown in the bottom part of **Error! Reference source not found.**. Similar to the first two evaluations, the players completed the same pre- and post-intervention questionnaires. In addition, the players were asked to complete an additional post-intervention questionnaire, consisting of 15 questions, that addressed the specific goals of the course and the complementary value of the game as a part of a theory course.

The knowledge questionnaire, pre-intervention background questionnaire and the post-intervention questionnaire for all four studies were similar, with minor changes in the formulations (Norwegian translations) of the questions. An overview of the number of questions included in the different questionnaires are provided in **Error! Reference source not found.**.

Table 2. *Overview of evaluation material*

Questionnaire	Number of questions
Knowledge questionnaire	16
Pre-intervention. Background questionnaire	20
Post-intervention questionnaire	21
Additional post-intervention questionnaire after the course	16

The data from the evaluations were analysed using simple statistical methods. The questionnaire data is correlated with session logs from the game play as relevant, to obtain deeper insights about the players' behaviours. The results discussed in this paper include a combination of data and analysis methods.

6 Evaluation of Learning

We have conducted four summative evaluations with operators, across four aluminium production plants. Two of the evaluations were based on pre- and post-intervention evaluations, where questionnaires and interviews were used. The other two evaluations were conducted, where the game was used as a part of a classroom course to support reflection. In total, 64 participants were involved in the summative evaluations. In both these cases, the trainer was able to observe and interact with the participants during the course.

The results from all four evaluations show that there was knowledge gain for most of the participants, i.e. 80 % of the participants, who completed both knowledge questionnaires. The mean knowledge increase was 61 %. There was a correlation between the level of knowledge gain and the pre-knowledge level of the participants; i.e. the participants that had low knowledge gain often had a high pre-knowledge level while the participants with a high knowledge gain had less pre-knowledge level. The knowledge gains were higher among the least experienced operators than the most experienced operators.

The results of the knowledge questionnaires for two of the studies are shown in **Error! Reference source not found.**. The vertical axis shows the number of correct answers and the percentage knowledge gain. The horizontal axis shows the participants. Note that the high negative values on the knowledge gain is due to blank or partly blank post-knowledge questionnaires that were submitted by some participants. A possible explanation for this could be that they felt they understood everything and therefore did not see any reason to complete the knowledge questionnaire a second time. The results from all four summative evaluations show knowledge gain.

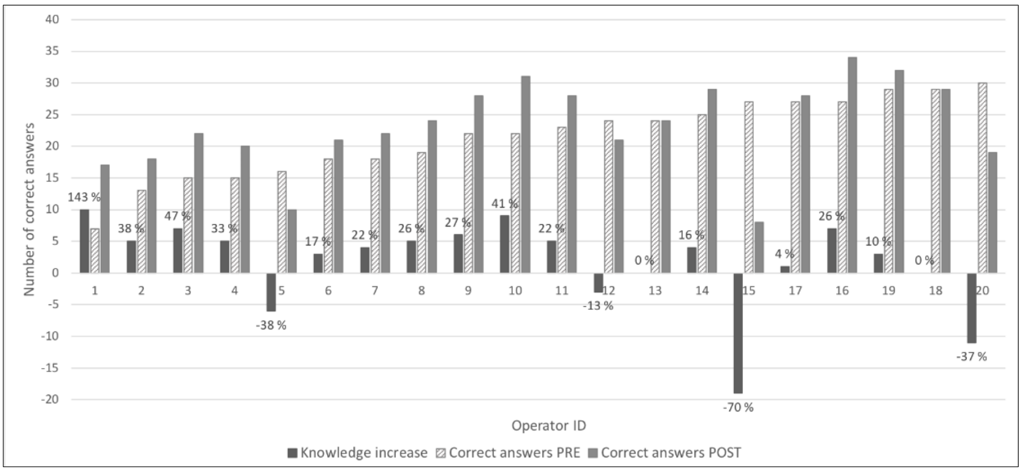


Figure 6. *Evaluation of learning – Operators play in their own time [39]*

7 Evaluation of Accelerated Learning

The evidence of knowledge gain from the pre- and post-intervention knowledge questionnaires is not sufficient to establish that the learning took place faster than any other means or if the amount of knowledge gained or the understanding was indeed greater within that time. In our project, it was not feasible to use control groups due to operational reasons within the company. In response to the constraints of conducting evaluation studies within real industrial settings involving operators with different levels of expertise, we used the ALF framework to design the pre- and post-intervention questionnaires to ensure that the criteria and the principles of accelerated learning were taken into account. Questions were included that addressed the three perspectives of ALF. In the following subsections, we discuss how ALF has been used to evaluate the potential for accelerating the learning process using the ALTT Heat Balance game.

7.1 Cognitive perspective

One of the most important feedback we have received from both formative and summative evaluations is that the game helped learners understand the dynamic process by seeing the causality of their decisions immediately, which was one of their cognitive challenges. The learners expressed that the most important role of the game was "*to be able to see the consequences of your actions*", and "*learn from your mistakes*". The game was designed to encourage a reflective practice, (as shown in **Error! Reference source not found.**), where the operators are expected to review the current status by looking at the history of the cell and to anticipate the consequences of their actions on the cell [38] (in-game reflection). Game logs from three studies show that learners use the support for reflection in the game; see **Error! Reference source not found.**.

The data from the session logs from the game were analysed to evaluate if the learners actually understood the consequences of their actions in the game. After each action in the game, three questions were presented to the player to stimulate reflection and anticipation of the consequences of their actions on the three process variables bath temperature, acidity and superheat; the three questions are shown in **Error! Reference source not found.**. The three graphs in **Error! Reference source not found.** show the average responses to the three questions from three of the studies where the players were given access to the game to play in their own time. The green bars (at the bottom of the graphs) show the correct answers; the brown bars (on the top of the graphs) show the incorrect answers and the white bars (in the middle) show an error by one. It can be seen that there is a higher percent of correct answers than incorrect ones. Since the percentage of correct answers is higher than 33%, it can be assumed that players were not randomly selecting an answer but making a conscious choice of the correct answer. Players seem to understand the concept of temperature better than acidity and superheat and this is consistent across the three studies. In addition, the post-intervention questionnaires from the studies show a positive response towards the functionalities in the game to support reflection. For the statement "the game can help me reflect better on what I have learned in the HB course", 78% strongly agreed or agreed; see **Error! Reference source not found.**.

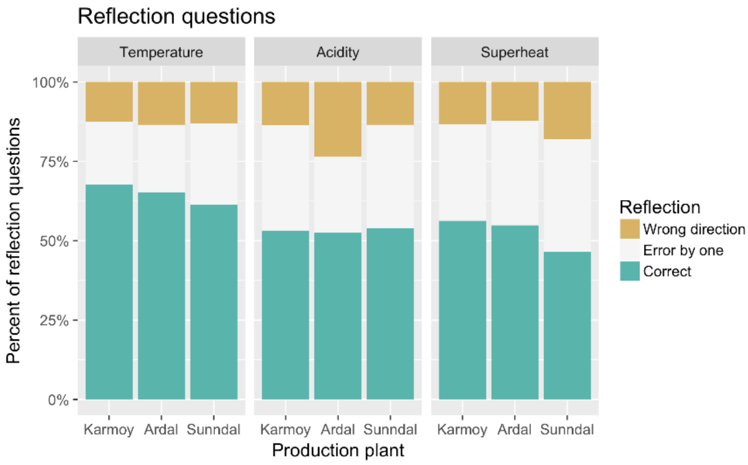


Figure 7. *Understanding and in-game reflection using game logs*

Creation and not consumption were considered in the interactive game design and by adding functionality to make the players take intentional actions. An example of this is the functionality to stimulate reflection as discussed above. The preferred learning style was evaluated by asking the learners, in both the pre- and post-intervention questionnaires, if they think that games are a good way to learn. The data shows that over 80% of the participants either agree or strongly agree; see **Error! Reference source not found.**. While the results from both the pre- and post-intervention questionnaires are positive, there is a slight decrease in the overall percentage of responses in the post-intervention questionnaire that strongly agree and agree to the statement. We assume that this could be due to some specific expectations that were not met by the game or the choice of the target learner groups. In fact, the participants of the studies spanned from the very experienced to novice operators and therefore it can be assumed that their expectations of the game would vary. Data from the questionnaires and the session logs show a correlation between the preferred learning style and the amount played by the participants; **Error! Reference source not found.** shows that the participants that strongly agreed and agreed that games are a good way to learn played more than those that were undecided.

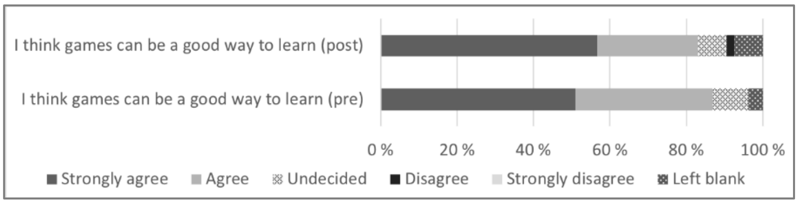


Figure 8. *Preferred learning style from Pre- and Post-intervention Questionnaires*

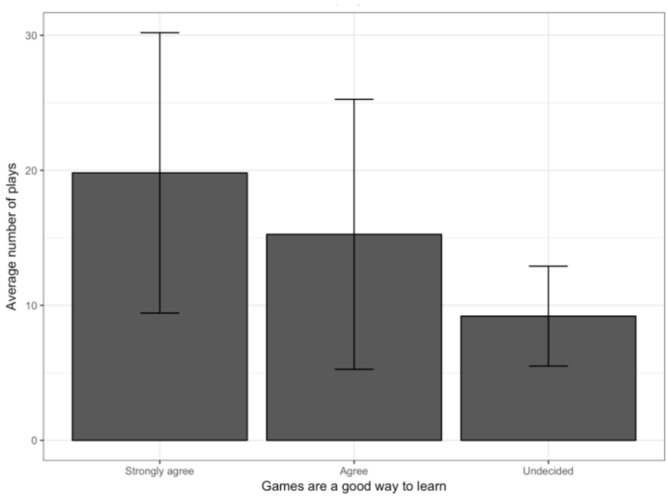
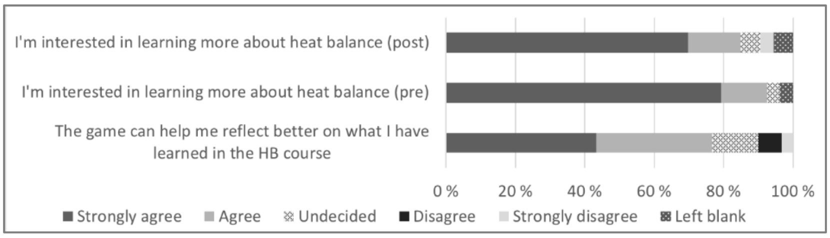


Figure 9. *Correlation between preferred learning style (Questionnaire) and game play (session logs)*

7.2 Affective perspective

Observations during all studies indicated engagement by the learners (note that observation and talk aloud were used as methods during most of the formative/iterative design related studies). Five game scenarios were available when the formative and summative evaluations were conducted. During the formative evaluations, the participants were asked to play for about 30 minutes. However, several participants were engaged in playing the game after 30 minutes and continued in discussions about the game.

Emotional engagement, attitudes and motivation were evaluated using questionnaire data which indicate a positive attitude towards learning about Heat Balance, an increase in the learners' confidence and perceived understanding. Several statements were included in both the pre- and post-intervention questionnaires and the responses show positive results (see **Error! Reference source not found.**). For the statement "I'm interested in learning more about Heat Balance", over 80% of the participants agree or strongly agree, although the post-intervention results were less positive than the pre-intervention results.



ISSN: 2384-8766 http://dx.doi.org/10.17083/ijsg.v6i3.314

Figure 10. *Attitudes and interest in learning Heat Balance (from questionnaires)*

It is interesting to see that correlations between the questionnaire data and the session logs show that the participants that responded "undecided" in the Likert scale played more than the ones that responded "strongly agree" or "agree"; see **Error! Reference source not found.**. This implies that although the respondents were not interested in learning more about Heat Balance, they must have found the game interesting or relevant for their understanding and their work and perhaps the game has the potential to stimulate an interest in learning.

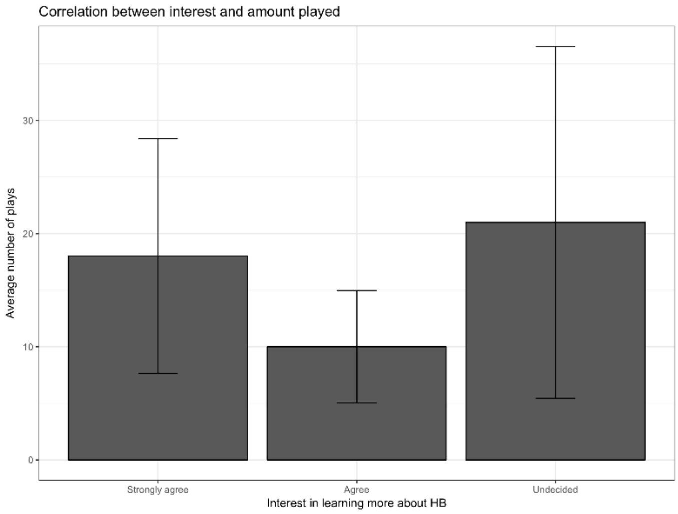


Figure 11. *Correlation between interest in learning (questionnaire) and game play (session logs)*

Over 70% agreed or strongly agreed that they understand the basic concepts and relationships better after playing the game. The responses to the statement related to learners' confidence, "I am confident that I can determine if a cell has a deviation associated with HB", show an improvement in the post-intervention results; see **Error! Reference source not found.**.

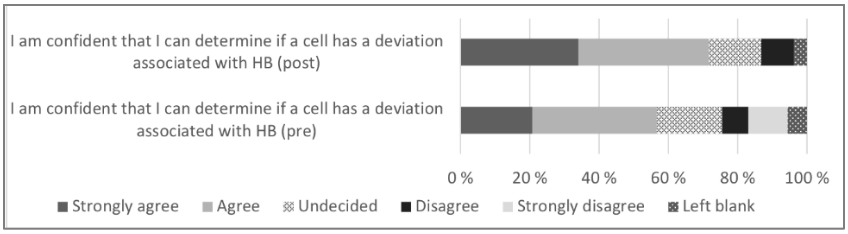


Figure 12. *Players' confidence (from questionnaires)*

Interviews and questionnaire data show that learners were positive towards the feedback and hints provided in the game. Feedback was provided within the game in many ways; e.g. by showing how the anticipated consequences of their actions differed from the actual consequences (see **Error! Reference source not found.**), and by letting them know when they were one or two turns away from winning the game. Hints were provided as information icons and suggestions when they were repeating the same mistake. At the end of each game scenario, the player is provided a score and feedback as stars and glitter and several participants found this visual feedback encouraging. The final score for the game is based on two elements; the responses to the reflection questions shown in **Error! Reference source not found.** and a score based on the difference between the number of turns it took the player to win the game and the optimum number of turns to win the game. This is shown in **Error! Reference source not found.**, where the left hand side of the figure shows the final score for the reflection questions and the right hand side shows the score for the number of turns to win the game. In this particular example, the player had managed to win the game with the optimal number of turns although the score for the reflection questions was only 44%. Several players expressed that the part of the score that indicated their responses to the reflection questions was particular helpful for their learning. This example illustrates that players could actually perform very well in the game without necessarily reflecting upon the consequences of their actions or understanding the concepts. Thus, the feedback on the different aspects of learning is important for supporting acceleration of learning.

Figure 13. *Display of final score (in Norwegian). English translation: left hand side: Quiz results; right hand side: Scenario completed. You completed after 3 rounds. The optimal number of rounds for this scenario is 3.*

7.3 Context

Usefulness and transferability of what is learned from the game to the daily work are two important concepts to relate to the context of learning and the workplace. Transferability and a realistic game were design requirements and the iterative design and evaluation approach ensured these. The dynamic process model and the simulations from the model visualised by the graphs on the user interface made the game realistic, thus supporting easy transfer of what is learnt in the game to the real work situation. Furthermore, the game scenarios are created by using historical data from the operations of the aluminium production cells (furnaces), ensuring realistic scenarios that the operators may have experienced in the past or may likely encounter during their working life.

Post-intervention evaluations show that the learners think they can use what they have learned from the game in their work and they can relate the contents to their daily work, (see **Error! Reference source not found.**). Over 60% of the learners agreed or strongly agreed to the statement "I can relate the contents of the game to my work". Similarly, over 70% of the learners agreed or strongly agreed to the statement "I think I can use what I've learnt from the game in my work". These results are based on the participants' perceptions, through self-reporting. It is indeed not the same as evidence in the participants' performance in the workplace or observations in the workplace or impacts on the operations. It has not been possible to gather such data related to the transferability of the concepts from the game at the time of writing. However, this will be a part of the future work.

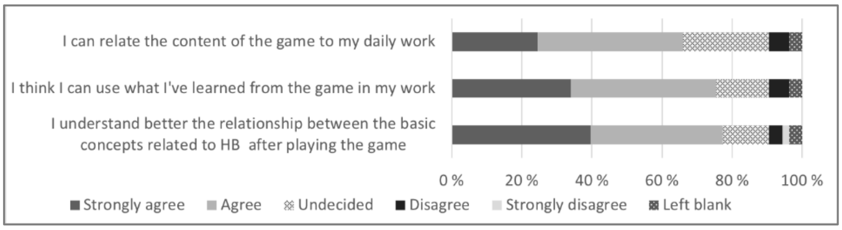


Figure 14. *Transferability and usefulness of the game (Questionnaire)*

Learning by doing was evaluated using open-ended questions in the studies where the game was a part of a classroom course, to support reflection. The data indicates that the game complements the theory by enabling the learners to experience trial and error in the game environment. Over 75% of the participants agreed or strongly agreed to the statement "I understand better the relationship between the basic concepts related to HB after playing the game"; see **Error! Reference source not found.**. One learner expressed that "*it's much easier to understand the theory when one gets to test oneself*".

The current version of the game is designed primarily for supporting individuals rather than social and collaborative learning. However, the participants have expressed that playing in pairs and using the game to support discussions and collective reflection among peers is helpful to their understanding. In addition, the expert users, who often take a mentor role for the novices, have identified the game as an important medium to help the novices understand the dynamic process and the complex dependencies and expressed a need for the game to support discussions at the workplace. The visualisation of the cell in different ways (e.g. the graphs, the 9-box model and others) that relate theory and operations (the graphs are what they use at work) support understanding and transfer of the knowledge.

8 Conclusions and Future Work

Frameworks for the design and evaluation of serious games exist and most of them focus on the evaluation of learning. While GBL claims it can accelerate learning, there are no frameworks that explicitly address this. This paper presents a framework for evaluating accelerated learning, ALF, where the cognitive, affective and contextual perspectives and the synergies among them were central concepts of the framework. The main research question addressed in this paper is how can we evaluate accelerated learning in GBL environments at the workplace? The use of the framework is described using the results from four summative evaluations with the end users.

The evaluations were conducted with operators at their workplaces, at four aluminium production plants. The evaluations that could be conducted were constrained due to operational reasons. ALF was particularly helpful in designing the evaluation material, to evaluate if the ALTT Heat Balance game had the potential to support accelerated learning. The different perspectives addressed by ALF ensured that factors other than knowledge gain were considered. This is particularly relevant for workplace learning as the applicability and usefulness of the knowledge is absolutely necessary for the operators. Similarly, a realistic game design and the transferability of the knowledge to the real workplace is important in supporting the applicability of the new knowledge. Furthermore, ALF raised awareness in evaluating the cognitive and effective perspectives which contribute to the learning process.

The overall results from four studies conducted across four aluminium plants show that the participants increased their knowledge from playing the game. Furthermore, the evaluation material that specifically addressed accelerated learning, the cognitive, affective and contextual perspectives, show that the ALTT heat balance game has the potential to support accelerated learning. The game supported reflection during the game play, in selecting actions within the game, and the participants attitudes to learning and confidence in their competence increased through playing the game.

One of the strengths of the project and the evaluations was the close collaboration with the domain experts and end users from the aluminium company during the different phases of the game design and development. The game has been tried by a number of expert and novice operators. It has been a tremendous advantage in having the opportunity to conduct evaluations with the actual end users and get direct feedback from them. Having said that, one of the limitations of the studies, which was the lack of possibilities to conduct controlled experiments, was a consequence of conducting evaluation studies in a real work setting. Nevertheless, the evaluation results show clearly that the game has the potential to accelerate learning.

The ALF framework itself emerged simultaneously with the design of the game and the evaluation studies. This is perhaps not uncommon in industry and innovation projects.

Nevertheless, since the game had an iterative design process, the central ideas of the framework influenced the design of the game and the evaluation method and material. ALF has not been validated explicitly at the time of writing. However, since ALF was found to be useful in the design of some of the game elements, the evaluation material and evaluation of learning, can be considered as a first attempt at validating ALF. We are currently working on a comprehensive validation of the framework.

Based on the results we have so far, further evaluations studies are planned with focus on other aspects of accelerated learning using games, such as retention of knowledge. In future evaluations, we also plan to address specific issues with specific user groups.

Acknowledgements

This work has been conducted within the ALTT project funded by the BIA program, Norwegian Research Council. The authors would like to thank the project participants from Hydro, Attensi, Cybernetica and SINTEF, participants of the workshops and evaluation studies, the operators and the experts from Hydro who have provided valuable feedback through discussions and evaluations. The authors would also like to thank Andreas Landmark and Hans Torvatn, from SINTEF, for their contributions with the questionnaire design and data analyses.

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