Review of simulator training practices for industrial operators: How can individual simulator training be enabled?

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Abstract

The aim of simulator training is to improve the safety and integrity of operations. Effective simulator training involves relevant feedback and sound assessment of the operator's performance. Operators need proper feedback to be able to identify and fill gaps in their competency or learn new practices. Appropriate feedback and assessment are of great importance to ensure that process operators have the competences required to ensure smooth and safe plant operation. Consequently, delivering effective training and evaluation represents a very significant challenge for the process industry. Further, the availability of on-site simulator training is often very limited and the costs related to it are high. Therefore, individual simulator training, in addition to team training, can be a practical option to be considered. This article presents a thematic analysis of simulator training practices in different industries. The findings suggest that individual training can be implemented as a supplement to on-site training, that effective feedback and assessment are necessary, and that the training should be based on a human-centric perspective.

Keywords: simulator training, operator training, individual simulator training, off-site training.

1 Introduction

Simulator training consists of learning and developing different skills by using computerized models that can emulate a variety of real phenomena and processes. As a learning strategy, simulator training promotes transfer, which, according to Perkins and Salomon (1992), "occurs when learning in one context or with one set of materials impacts on performance in another context or with other related materials." Research by Spetalen and Sannerud (2015) indicates that simulation can be a suitable strategy for achieving close transfer, given context similarity and a connection between tasks in the simulation and the application context. Simulator training has many benefits, and it has been widely implemented among industrial operators since the 1990s. Simulators for training industrial operators are known as Operator Training Simulators (OTSs) (Patle et al., 2014). OTSs are based on dynamic simulations of industrial processes. The simulation software available in the market includes Aspen Dynamics & HYSYS Dynamics from Aspen technologies; ASSETT and K-Spice from Kongsberg Oil & Gas Technologies; TSC Sim from TSC Simulation, UniSim from Honeywell, and OLGA from SPT Group (Patle et al., 2014).

References to simulator training for industrial operators mainly concern on-site training. This means that the operators have to travel to the training facilities, where training takes place in a room that replicates the actual control room with all the necessary equipment (hardware and software) (Kluge et al., 2014). It also includes a user interface that shows a distributed control system (DCS) resembling the real process. This allows the operator to learn and understand the process by practicing different scenarios (Kluge et al., 2014, Nazir et al., 2015b). Usually, this is the only place where a simulator is available to the operators; all training they do is carried out at the designated location, where they are guided by and receive feedback from an expert instructor. During simulator training, the operators can practice handling different scenarios, such as malfunctions, troubleshooting, abnormal or emergency conditions (Komulainen et al., 2012, Kluge et al., 2014, Patle et al., 2014). In many cases, the scenarios have to be solved in groups, with the aim of improving team skills. During the training, each operator has her/his own computer that interfaces the same process model, as in the actual plant where each operator has her/his work station that interfaces the same DCS. This is the traditional way in which simulator training is carried out. However, even though extensive research exists that discusses the benefits of this type of simulator training approach (Asbjörnsson et al., 2013, Kluge et al., 2014, Patle et al., 2014, Salas et al., 2012), several factors suggest that operator-training methodologies need to be improved. For instance, throughout the training, operators have to adapt to the rhythm decided by the instructor or to the flow of the training session that arises together with their colleagues. In the case of team training, it is difficult to award individual scores to the operators. Further, the time the process industry allocates per year to simulator training sessions is very limited (Komulainen and Sannerud, 2014). In the case of Statoil ASA in Norway, the training time allocated for expert operators is two days a year; for novice operators, it can be five days a year (Nordsteien, 2015). The availability of expert instructors is limited as well, and one instructor can only train four or six operators at the same time. Therefore, some of the training tasks may not be completed, and the quality of the training may be affected. Moreover, in the last decade, there have been major developments in advanced process control technologies, which means that operators at industrial plants encounter strong challenges due to the complexity of the highly interconnected processes, the high information load of the control and safety systems, and other related technologies (Nazir et al., 2014, Zou et al., 2015). Limited training time, together with technological challenges, increases the probability of human errors, which, in turn, can lead to industrial accidents (Nazir et al., 2012), many of which occur every year (Koteswara and Yarrakula, 2016, Bureau of Labor Statistics, 2016, Eurostat, 2017). It seems that the solution to this industrial vulnerability does not rely entirely on the implementation of advanced automation; it is also related to learning methodologies and training time. Technological development aimed at achieving automated control of industrial operations leads to an increased need for new and improved methods for training operators – to ensure that they are competent and skillful enough to properly meet the high requirements of automated systems. In order to identify how to enable individual simulator training practices that could reinforce the traditional training methods for operators, a review was carried out of various articles relating to industrial simulator training.

The rest of the paper is organize as fallow: the second section presents contextual information, being this: what is meant by individual simulator training and which technologies already exist that offer individual training. These technologies will be analyzed from a pedagogical perspective to identify how they can be implemented to support individual simulator training. The next section describes the methodology followed for the literature review. Findings are presented in Section 4, and the analysis of the findings is presented in Section 5. Finally, some conclusions are drawn in Section 6.

2 Contextual information

2.1 Individual simulator training

Before proceeding, it is necessary to explain what is meant by individual simulator training. As the name implies, individual simulator training is not focused on teams, but rather on the individual. Team training is already taken care of during on-site training at the training facilities. Individual simulator training refers to the implementation of suitable technology and learning strategies that enable operators to:

- develop individual technical skills,
- have access to off-site simulator training whenever they feel they need it,
- train on the simulator until they have completed all the recommended training tasks,
- refresh previous knowledge they may be in doubt about due to infrequent use.

2.2 Individual training technologies

There exist different technologies that allow individual training; a pedagogical analysis of these technologies can show how they can be implemented to enable individual simulator training. The pedagogical analysis was done using Bloom's taxonomy, which is a suitable classification system to categorize cognitive skills. It was introduced in 1956 by Benjamin Bloom and colleagues as the Taxonomy of Educational Objectives (Bloom, 1956). In 2001, a revised version of the taxonomy was presented by Krathwohl (2002). Bloom's taxonomy is a model for classifying statements about what students are expected or intended to learn from specific training (Krathwohl, 2002). It consists of six main categories in the cognitive domain, which, in the revised version, are: remember, understand, apply, analyze, evaluate, and create. A pyramid illustrating the categories is shown in Figure 1. The categories are organized hierarchically from simple at the bottom of the pyramid to complex at the top. In connection with the present rapid technological evolution, the name Bloom's digital technology has been introduced (Common Sense Education, 2016, Churches, 2008). The term has been coined from the perspective of how technology affects the model; in this sense, the focus should not be on the technological tools themselves, but rather on how the tools can help to foster each of the cognitive levels in Bloom's taxonomy (Common Sense Education, 2016). Given that Bloom's taxonomy is a very well known model, and one of the most used tools in the pedagogical field, it was selected as the basis for the analysis of the individual training technologies.

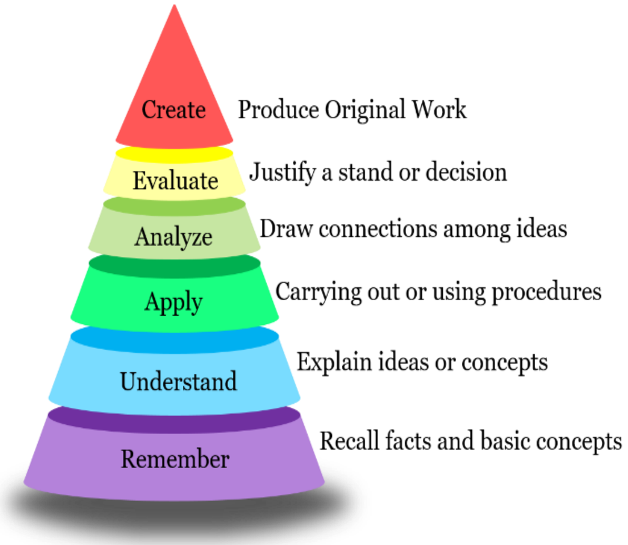

Figure 1. Revised Bloom's taxonomy (Krathwohl, 2002, Vanderbilt University Center for Teaching, 2016).

Which technologies can promote individual training, then? Some of the most relevant examples are mentioned below. In addition, Table 1 shows which cognitive levels of Bloom's taxonomy are supported by these technologies.

In general, *e-learning* refers to learning via electronic information frameworks that allow the user to access information that is available without limitations of time or space (Aparicio et al., 2016). Alexander and

Table 1. Cognitive levels supported by individual training technologies

Category	Individual training technology
Create	• e-learning (4th level)
Evaluate	• e-learning (3rd level) • ITS • Simulator training
Analyze	• e-learning (3rd level) • LMS • ITS • Simulator training
Apply	• ITS • LMS • Simulator training
Understand	• e-learning (2nd level) • LMS • Instructional videos
Remember	• e-learning (1st level) • Instructional videos

Cosgrove (1995) defined a four-level model of e-learning, Chang (2016) explains each level as follows:

- First level: online presentation and publishing
- Second level: online quizzes and assessment
- Third level: online forums, opportunity to give and receive feedback and participate in open discussions.
- Fourth level: role-play, face-to-face presentations, discussions, and online debates.

Based on this four-level model, e-learning can support several categories in Bloom's taxonomy (Table 1). The first e-learning level is where learning material and information are found. This level therefore supports the lowest category of Bloom's taxonomy, *remember*. The next e-learning level is associated with quizzes and assessment; here, students should explain what they have understood from the information acquired, thus supporting the second category of Bloom's taxonomy, *understand*. In the third level of e-learning, students need to *analyze* what they have learned in order to be able to participate in open discussions. They should also be capable of criticizing and *evaluating* what others say in order to be able to give them feedback, thus supporting the fourth and fifth categories of Bloom's taxonomy, respectively. Finally, the last level of e-learning supports the highest category of Bloom's taxonomy, *create*, since role-play, presentations and online-debates require the production of new and original work (Table 1).

E-learning is implemented in many different fields, such as lower and higher education, the corporate sector, industry, and health care (Cheng et al., 2014).

In the case of individual simulator training for industrial operators, e-learning could be very useful, especially for novice operators, since they are learning new concepts and how to understand the plant. Using e-learning, operators could have access to the necessary information at all times; they could consult the material whenever need to, no matter where they are. Moreover, they could participate in forums where they can discuss the process with their peers or with instructors when available.

Learning Management Systems (LMSs) provide the virtual platform for e-learning. Among other features, they enable management, monitoring of students, tracking of learning, testing, communication, and scheduling. They offer many time-saving utilities that are very useful for instructors (Cavus, 2015), who, as a result, are satisfied with the implementation of this technology (Almarashdeh, 2016). Moreover, LMSs enable students to organize their training time and to adapt the training to their personal requirements (Ramírez-Correa et al., 2017). LMS implementations can be found in small businesses and even the health care sector. However, they are most commonly implemented in higher education; examples include Edmodo, Moodle, and Blackboard.

LMSs support the second cognitive level of Bloom's taxonomy (*understand)* through testing and communication. Further, the opportunity they give students to organize and schedule their own learning also situates LMSs in the third and fourth categories of Bloom's taxonomy, *apply* and *analyze* (Table 1).

LMSs can be a great help in the training of individual operators because they make it possible to remotely keep track of each trainee. The instructor can monitor the operators' performance and progress at all times, and the operators can be informed about their development, and keep track of which scenarios they need further practice in. LMSs could be very useful for novice and even expert operators. In the case of novice operators, they need constant monitoring and to practice more often, both of which can be achieved with an LMS. In the case of expert operators, LMSs can include tasks they could practice on and thereby refresh procedural scenarios; an instructor can remotely monitor that the operators have carried out the required activities and give them feedback when possible. This idea is presented by Bessiris et al. (2011), who propose an LMS for long-distance operator training.

Intelligent Tutoring Systems (ITS) refers to a type of computer tutoring in which the learner is given feedback and hints. This is done via a user interface that allows the learner to enter the steps required to solve a certain task (VanLehn, 2011). Polson and Richardson (2013, p.1) explain that an ITS must pass three tests of intelligence. First, it must have sufficient information, "knowledge", about the subject matter to be able to draw inferences or solve problems in the domain. Second, the system must be able to determine the learner's absorption of that knowledge. Third, the tutoring strategies or pedagogy embedded in the system must function in such a way that the ITS implements these strategies to improve the learners' performance. ITSs are mainly implemented for academic purposes; in elementary and secondary education (Huang et al., 2016, Wijekumar et al., 2013), and in higher education, such as engineering (Hooshyar et al., 2016, Huertas and Juárez-Ramírez, 2013, Khalfallah and Slama, 2015, Ramírez-Noriega et al., 2017), and medicine (Sehrawat et al., 2013, Wolfe et al., 2016).

ITSs support the third, fourth and fifth cognitive levels of Bloom's taxonomy, which correspond to *apply, analyze,* and *evaluate* (Table 1). Using ITSs, students have to execute procedures and implement what they know to solve tangible problems. Furthermore, high analytical and decision-making skills are required to perform the different tasks that can be practiced on an ITS.

An ITS would be the most appropriate tool for individual simulator training because it offers automated feedback. In the case of the other learning technologies mentioned (e-learning and LMS), even though they offer the possibility of feedback, they still depend on an instructor being available, which is not the case with ITSs. ITSs could be especially useful in the training and guidance of novice operators, but they could also guide expert instructors through complex tasks by giving them automated intelligent suggestions.

Instructional videos, also called educational videos, are becoming a very common learning tool. Wang and Antonenko (2017) indicate that this is due to the continuous growth of online learning. Consequently, it is imperative for educational/training institutions to support users in online learning environments. Instructional videos are an example of the current tools that help to reach online learners. Instructional videos are used in medical education in particular (Kon et al., 2015, Phillips et al., 2016, Rapp et al., 2016). Nevertheless, instructional videos are now also available about a great number of topics in a wide range of fields. Massive open online courses (MOOCs), such as Khan Academy, edX, and coursera, are good examples. YouTube is an even simpler and more accessible example. Instructional videos aim to teach and help students to understand concepts and procedures. Hence this technology is situated on the first and second cognitive levels of Bloom's taxonomy, which are *remember* and *understand* (Table 1).

Instructional videos are a smart way of explaining new concepts and demonstrating how to perform different activities; they could also be a good help in individual training. For example, well-produced videos could teach novice operators about the functions of the simulator, and they could show trainees how to perform different training scenarios. The operators could practice remotely on the simulator while following the instructions given in the video.

These four technologies are an example of the variety of existing tools that support individual training, and any or all of these tools, combined with simulator training, could result in a sound and effective individual simulator training system that enables trainees to reach the highest cognitive levels explained by Bloom's taxonomy.

3 Methodology

A literature review and a thematic analysis were carried out of 32 articles published during the period 2007 and 2017. The aim was to identify gaps in simulator training within traditional practices that could be filled by individual simulator training. Another aim was to identify relevant methodologies, features, and conditions that could facilitate individual simulator training. The literature studied was gathered from the following electronic databases: Science Direct, EBSCOhost, Scopus, and Taylor & Francis. The search strings used were: simulator training, process industry, training methods, and control room operators. The literature was supplemented by relevant publications found in the reference lists of the selected articles.

This paper explores the methodologies used for the implementation of simulators as training tools and how traditional practices could be improved by including individual training. A total of 65 articles were extracted from the literature search. All the publications that addressed the topics of simulator training implementation and methodologies, training strategies within the process industry, and evaluation of training performance were selected for the study. Of the 65 articles, 32 had the required characteristics.

Of the 65 articles extracted from the literature search, 33 were removed for the following reasons. A significant number of the articles are related to the design and development of operator training simulators (OTSs) (Ahmad et al., 2016, Gerlach et al., 2015, Duca and Tamas, 2012, Pereira et al., 2009, Balaton et al., 2013). Many of them were not included because they mainly focus on mathematical modeling and the technical development of OTSs, which is not the focus of this study. Rather than how OTSs are designed, we wish to focus on whether effective use is made of them based on relevant learning methodologies. In other cases, the articles focused on the study of teamwork

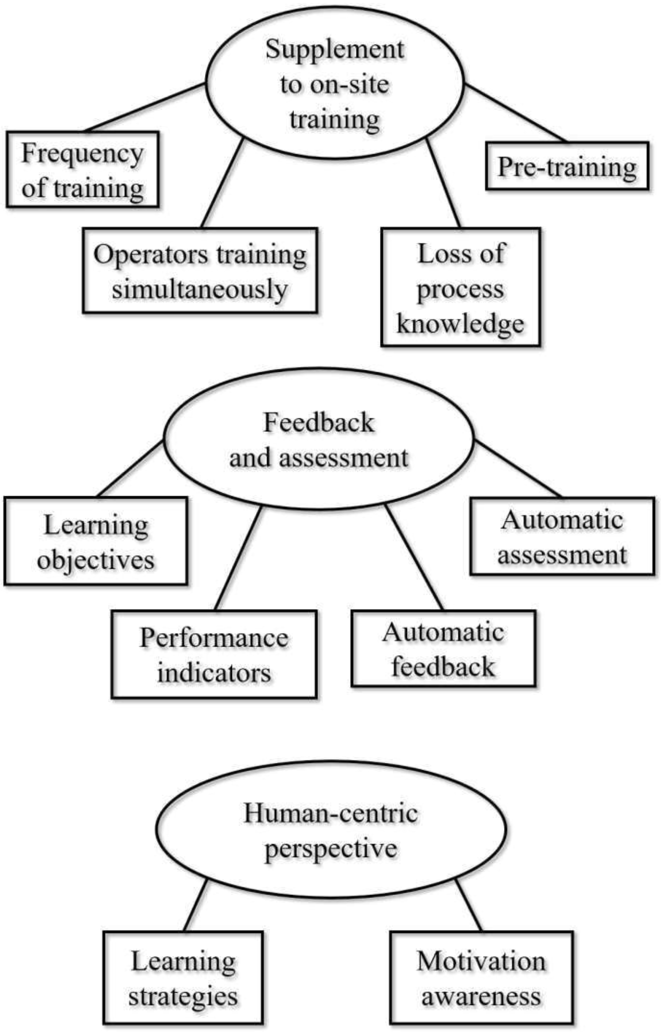

Figure 2. Themes found by means of thematic analysis.

training (Gao et al., 2015, Kim and Byun, 2011, Yim and Seong, 2016), which is not the main interest in this article; this study focuses on determining the path to enabling individual training when necessary. Articles were also found that focused on finding the cause of risk or emergency situations in industrial processes, based either on the analysis of human factors or on the design of the simulators (Li and Harris, 2013, Brambilla and Manca, 2011, Ikuma et al., 2014, Kim et al., 2016). Articles of this type were also excluded because they were outside the scope of this paper.

The method used to analyze the selected literature was thematic analysis, which is a method that consists of identifying and analyzing patterns or themes within data (Braun and Clarke, 2006). This method was chosen due to its flexibility and usefulness for summarizing key features across a data set (Braun and Clarke, 2006). Further, it is a multidisciplinary method (Milch and Laumann, 2016, Salleh et al., 2017, Teruel et al., 2016), an indication of its soundness and reliability. The selected literature was imported into NVivo 11 and it was coded following the steps indicated in Braun and Clarke (2006). The first stage of the analysis of the publications consisted of reading the articles and getting to know the themes addressed. A number of themes within the material were coded, the result of which is very broad. Later, the codes were refined and grouped into more specific themes and sub-themes.

4 Results

The reviewed literature shows a wide range of themes. The most common one in the majority of the literature studied is the benefits of simulators. Advantages of simulators include realistic virtual environments, training flexibility, process understanding, training in emergency or rare situations, practice in standard operating procedures, etc. (Alamo and Ross, 2017, Gerlach et al., 2014, Kluge et al., 2014, Manca et al., 2012b). However, even though they are relevant, the benefits of simulator training were not the main concern of this paper, given that this is an already well-known subject. The focus was on finding how to enable individual simulator training. This section presents the results from the thematic analysis of the literature. The thematic analysis resulted in three themes, each containing several sub-themes: *supplement to on-site training, feedback and assessment,* and *human-centric perspective*. An overview of the themes is shown in Figure 2.

4.1 Supplement to on-site training

The literature indicates areas in which individual simulator training can be integrated in order to supplement traditional practices for simulator training: *frequency of training, operators training simultaneously, loss of knowledge,* and *pre-training*. They are addressed in the following.

4.1.1 Frequency of training

The frequency of training is not a very common subject in the literature. It is not usually stated how often the operators train on the simulator or for how long. Nevertheless, it was possible to draw a conclusion from the material. The literature suggests that the frequency of on-site simulator training is very low. Normally, simulator training takes place once a year (Idrees and Aslam, 2010, Kluge et al., 2009, Ritz et al., 2015, Komulainen and Sannerud, 2014) and it can last for from three to five days (Bronzini et al., 2010, Håvold et al., 2015, Kluge et al., 2009).

4.1.2 Operators training simultaneously

During on-site simulator training, the number of operators that can be trained at the same time is contingent on the architecture of the training room, which is usually as similar as possible to an actual control room (Kluge et al., 2014, Manca et al., 2014, Nazir and Manca, 2015, Patle et al., 2014). This means that, depending on the process, the number of operators who can use the simulator simultaneously varies between two and six. Bessiris et al. (2011) point this out as one of the disadvantages of traditional simulator training sessions, given that, for large-scale processes, there can be high demand for operator training. In this article, they proposed a "Corporate OTS" approach that would enable remote training and the possibility of training a high number of operators at the same time. Concern about the number of operators that can train simultaneously on the simulator is also found in Vellaithurai et al. (2013), who suggest implementing a remote simulator tool that enables several operators to be trained at the same time.

4.1.3 Loss of process knowledge

Simulator-training instructors are typically expert operators, who are usually senior workers who have been controlling and learning about the process for many years. Their long careers and vast experience are the main reasons why they are experts. Therefore, it is of great concern in many industries that all of the knowledge acquired by experienced operators will be lost when they retire, without this knowledge being passed on to new operators (Dozortsev, 2013, Patle et al., 2014, Worm et al., 2012).

The loss of process knowledge in the industry due to generational transitions is one of the key motivations for research and development work on better and improved operator-training methodologies. Alamo and Ross (2017) argue that it is critical to ensure swift and adequate training for the remaining employees who will take over once the experienced operators retire, if the success of operating companies is to be maintained. Bronzini et al. (2010) also mention in their research that there is a great need for training of junior operators who have less on-the-job experience and must cover the positions previously held by experienced senior operators.

One approach to dealing with the loss of process knowledge caused by the retirement of expert operators is suggested by Manca et al. (2012a) and Nazir and Manca (2015). They suggest that it is necessary to develop an assessment tool that is reliable and repeatable. An assessment tool with these features must consist of standardized methods for operator training, and it must be based on certified and validated procedures, thereby ensuring that process knowledge is retained inside the plant. Vellaithurai et al. (2013) present an example of such a tool. They propose a system that learns by analyzing the corrective control actions taken by expert operators when using the simulator. Later, the system aligns the control actions calculated automatically with the data saved during the operators' interaction. Based on this, the system can present the experts' knowledge with precision.

4.1.4 Pre-training

Gerlach et al. (2014) carried out a research experiment where the performances of two groups of operators, one with pre-training and one without, were compared. The pre-trained group showed a better performance when following the SOP protocol than the group without pre-training. The authors concluded that pre-training on an OTS prior to the practical training in the plant enhanced the entire training process. Another example of the use of pre-training is found in Asbjörnsson et al. (2013). They developed an online training simulator for a crushing plant that was not yet built; they suggest that this would enable the operators to start training and be prepared for the ongoing training and actual management of the plant when it is operational. Dozortsev (2013) explains that operators carry out tasks that consist of multistage operations (e.g., detection of deviations from the norm, diagnosis of their causes, and planning and implementation of compensatory actions). He suggests that operators need to develop specialized skills for the different stages and argues that these skills should be developed during pre-training. The author also mentions Honeywell's Russian branch as an example of a simulator vendor that has developed a range of pre-training products in response to user requests.

Even though some examples of pre-training are found in the literature, it is not implemented regularly in traditional simulator training. However, in several of the articles, the authors suggest that the basic knowledge that each operator has of the process is a relevant factor that influences their learning and performance development when using the simulator (Asbjörnsson et al., 2013, Dozortsev, 2013, Gerlach et al., 2014). Therefore, it is critical to ensure that operators have the necessary basic knowledge before training how to handle complex processes and abnormal situations in the simulator. Prior knowledge of the process can reduce the cognitive load during ongoing training and thus lead to effective learning of new concepts and better performance (Bell et al., 2008). In conclusion, although not always explicitly, the literature reflects that it is essential to ensure that the operator has the necessary basic knowledge before starting formal simulator training.

4.2 Feedback and assessment

Feedback and assessment are key parameters of effective training (Salas et al., 2012). They are widely mentioned in the literature. According to Salas et al. (2012), timely, constructive, and diagnostic feedback makes the training more useful. Through clear feedback, the learning experience can be more effective; trainees can be guided to learn properly what is required, they can be guided to learn about the consequences of actions taken, and they can be guided to learn from errors

(Håvold et al., 2015, Kluge et al., 2009, Tichon and Diver, 2010).

Training systems and methodologies are developed with the aim of improving operators' skills. Thus, it is only reasonable that evaluation methods are implemented to determine whether the training results are successful or not, i.e., to determine whether the operator has achieved the training goals (Darken, 2009, Idrees and Aslam, 2010, Nazir and Manca, 2015). A thorough assessment procedure must be developed, and, to ensure the validity of the assessment, it must be capable of accurately determining and quantifying the skills operators have gained, their performance rate, and improvement (Bronzini et al., 2010, Dorey and Knights, 2015, Tichon and Diver, 2010). Further, assessment results mean that it can be determined whether or not an operator is well-prepared to work on the actual process (Vellaithurai et al., 2013), and they can be used to identify training needs and support the development of "tailor-made" training exercises (Håvold et al., 2015).

Nevertheless, although the importance of assessment is well reflected in the literature, several articles point out that there is a need for further research on the development of effective assessment methods for simulator training (Darken, 2009, Nazir and Manca, 2015, Nazir et al., 2015a). It is also mentioned that the assessment methods currently implemented in simulator training need to be improved. Bell et al. (2008) report that simulator trainees do not have an accurate assessment of their knowledge. This makes them overconfident about their skills, and, as a consequence, they underestimate the importance of training, which results in poor performance. Bessiris et al. (2011) mention that conventional simulators' poor ability to track and assess operators' performance is a weakness. Moreover, Nazir et al. (2015b) argue that another limitation of current training methods is the lack of objective performance assessment. Operator training does not usually involve systematic assessment methodologies; the evaluation of the operators is strongly influenced by the trainer's experience and perception of what is correct. Therefore, the evaluation is subjective and non-repeatable, and hence not very effective (Manca et al., 2012a, Darken, 2009).

As a supplement to the theme of feedback and assessment, three sub-themes linked to the subject were identified in the literature: *learning objectives, performance indicators, automatic feedback,* and *automatic assessment.*

4.2.1 Learning objectives

The idea behind training is to develop or reinforce specific skills and acquire specific knowledge. Therefore, simulator-training methodologies should be structured in such a way that the trainees are motivated to achieve the primary goals of the training process (Bell et al., 2008, Blake and Scanlon, 2007, Darken, 2009, Patle et al., 2014). Trainees need to be aware of the purpose of their training, so that they can orient their efforts towards achieving the learning objectives. Consequently, a logical assessment method must be centered on the learning objectives for the exercise, and it should be based on collecting relevant data that show whether or not the trainee has achieved the required goals (Salas et al., 2012).

Structured and clear learning objectives for training tasks form the basis for a comprehensive assessment, which, accordingly, leads to improvement and more effective simulator training.

4.2.2 Performance indicators

To be able to quantify or determine compliance with training objectives, special parameters that can express performance numerically must be defined. In the literature, these parameters are generally called performance indicators. However, in some research, the authors also refer to them as indexes or factors. Bronzini et al. (2010) define a Simulation Performance Index (SPI). They link a specific SPI to each training module and each index is determined using a reference value, which corresponds to the performance of senior operators. Park et al. (2017) use Performance Shaping Factors (PSFs) to determine Human Error Probabilities (HEPs). The authors state that each of these factors represents a particular aspect that may affect the operator's performance. On the other hand, indexes established to assess different trainees' characteristics are defined by Manca et al. (2012b) as Operator Performance Indicators (OPIs). They explain that the intrinsic human attribute in OPIs hinders evaluation of this type of indicator. Manca et al. (2012b) also state that the selection of OPIs depends on the training stage; some OPIs can be related to normal operating conditions and others to abnormal plant conditions. Therefore, OPIs must be defined according to the training circumstances. There are also Key Performance Indicators (KPIs), which are well-known industrial indicators, mainly associated with the process and plant performance (Manca et al., 2012a). The study and evaluation of well-defined KPIs leads to more readable and understandable performance analyses (Nazir et al., 2013). Another type of performance indicator is found in Nazir et al. (2015a), who define Distributed Situation Awareness Indicators (DSAIs), which are used to describe and measure the distributed situation awareness (DSA) of the operators during training. Based on these indicators, it is possible to study whether the operators are focusing their attention on the most relevant aspects of the training.

There are a great variety of performance indicators; they have to be defined thoroughly and within the training context. Well-defined performance indicators form the basis for a repeatable and objective assessment that enables the training level of the operators to be described in quantitative terms (Manca et al., 2012a). Furthermore, adequate and relevant feedback can also be based on performance indicator values.

4.2.3 Automatic feedback

There are many suggestions in the literature concerning automatic feedback in simulations. Several articles point out that prompt guidance should be given during execution of the simulation tasks, and not only after the simulation is completed (Bell et al., 2008, Malakis and Kontogiannis, 2012). Bell et al. (2008) suggest that adaptive guidance and support throughout the simulation can enhance learning outcomes. Hence, it is essential to develop effective feedback methodologies that can be embedded in simulator-based training (Bell et al., 2008). Similarly, Malakis and Kontogiannis (2012) conclude that integrating instructional guidance into simulators leads to more successful training. Moreover, Manca et al. (2014) suggest that the results obtained from automatic assessment procedures could be used to produce robust automated feedback, which may increase operators' motivation to train more frequently with the simulator.

4.2.4 Automatic assessment

With respect to automatic assessment procedures, the literature suggests that they must be based on objective and measurable parameters (Manca et al., 2012a) and they must be consistent and repeatable (Manca et al., 2012b). This guarantees that the evaluation of operator performance is objective. Automatic assessment allows the operators' performance results to be stored in a database, to which the instructors must have access, so that they can retrieve and analyze the results, and observe and compare the operators' improvement and needs. In this manner, automatic assessment can be beneficial for instructors as well (Manca et al., 2014, Manca et al., 2012b).

4.3 Human-centric perspective

In the context of this research, a human-centric perspective refers to actions that focus on users' needs or opinions when developing and improving technologies or training methodologies. In the case of simulator training, human-centric refers to the design and development of the necessary tools based on operators' needs and suggestions.

Bell et al. (2008) present their concern about how simulations are designed; they point out that most simulation products do not take account of the individual learning differences between trainees, and, as a consequence, only some of the users benefit from simulator-based training. Therefore, they argue that future research on simulation development must pay close attention to the learner-centered perspective. Darken (2009) discusses the same topic, reporting that many training systems are technology-centered. The author argues that training technologies change rapidly with time, so it is not convenient to base the design of training systems on them; he suggests that the development of training systems should be based on human performance instead. Moreover, Darken (2009) states that some desirable characteristics of training systems are that assessment is focused on the trainee, and that they are developed using a common language, so that others can build new systems on top. More recent research also mentions human-centric considerations, thus recognizing their importance (Bronzini et al., 2010, Dozortsev, 2013, Håvold et al., 2015, Patle et al., 2014).

Velez et al. (2013) present an example of the advantage of implementing a human-centric perspective in the development of training systems. They developed a training simulator using a user-centered methodology, and they concluded that involving users in the development process led to satisfactory results. Given that the users were experts from different fields, this resulted in an exhaustive evaluation of the model from different points of view.

The literature suggests that the quality of training depends on much more than just the technology that is used. Successful training also depends on the development of simulation designs and training exercises based on trainees' needs, user-friendly technologies that can be used by a broader range of trainees, and human factor considerations.

On the other hand, two additional sub-themes that are also based on human-centric perspectives were identified: *learning strategies* and *motivation awareness.*

4.3.1 Learning strategies

Research indicates that simulators are valuable and useful tools. Nonetheless, to exploit their full potential, simulator training should be combined with a structured and well-planned training program based on a reasonable combination of theory and practice and users' needs (Alamo and Ross, 2017, Blake and Scanlon, 2007). Unfortunately, these last components are often overlooked. Learning strategies, feedback mechanisms, and analysis of training needs are not sufficiently prioritized in the development of training programs (Darken, 2009, Malakis and Kontogiannis, 2012). The importance of learning strategies is that they are developed based on a human-centric perspective; they involve structured thinking about the best methods for trainees to learn and retain new skills. Learning strategies allow trainees to get a better sense of the simulator and improve their use of it. Well-established learning strategies enable better understanding and longer retention of the information gained during training.

The literature presents many different learning strategies. However, only those found relevant to individual simulator training were selected for discussion in this paper. Table 2 presents a summary of the selected learning strategies.

Drill and practice (D&P) consists of practicing a task continuously with the aim of gradually improving performance (Burkolter et al., 2010). In D&P, trainees are systematically guided through the correct execution of the tasks. This thereby promotes the acquisition of procedural skills (Burkolter et al., 2010, Kluge et al., 2009). Further, the research of Burkolter et al. (2010) revealed that D&P is an effective method for developing the skill of diagnosing common fault states, and is thus especially favorable for the training of novice operators.

Kluge et al. (2014) indicate that learning to handle complex systems takes place through the accumulation of instances, which can only happen through experience or practice-based training. Practice-based training enables operators to acquire the necessary instances and mental models that build their knowledge of the process.

Emphasis shift training combined with situation awareness training (EST/SA). This method consists of combining two learning methodologies, EST and SA training. In EST, the priorities of the elements of a task change often, which requires voluntary control of attention. It mainly consists of learning to handle several tasks simultaneously (Burkolter et al., 2010, Gopher et al., 1989) (Kluge, 2014, pp.127-129). SA refers to the perception and understanding of the components of the environment and estimation of how the situation will develop in the short term. Mechanisms for redirecting attention to what is of interest can support the development of SA. SA training leads to the improvement of decision-making skills and event prediction (Burkolter et al., 2010).

Transfer appropriate processing refers to the idea that the difficulty of training conditions should increase as the trainees begin to master the required skills. The trainees should receive less support from the instructors and the tasks practiced should resemble the actual work more (Salas et al., 2012) (Kluge, 2014, p.125).

Error training consists of exposing the trainees to making errors, so that they can learn from the consequences of their actions. Error training encourages trainees to make a greater effort to learn and enable a deeper understanding of the training tasks (Kluge et al., 2009, Salas et al., 2012).

This kind of training gives trainees freedom to test and experience actions that might be too risky to try in the actual plant. Trainees can examine the effect that their decisions have on the process, and, in the case of possible errors, they can correct them and learn from them. Salas et al. (2006) suggest that there are two sub-components of error correction: self-correction and supported correction. In the case of self-correction, trainees study the errors by themselves without any guidance from the instructor or any other aids (Salas et al., 2006), thus developing their own strategies and increasing their resilience. With supported correction, on the other hand, trainees can receive directions and feedback to help them (Salas et al., 2006). Lorenzet et al. (2005) indicate that guided error training combined with supported correction may be the best combination for improving skills development. Salas et al. (2012) recommend the implementation of error training, especially when practicing complex cognitive tasks.

Table 2. Learning strategies

Learning strategies	Characteristics
Drill and Practice (D&P)	• Continuous practice. • Procedural skills and instances. • Novices training. • Experienced operators case (further research needed).
Emphasis shift training combined with situation awareness training (EST/SA)	• Management of several tasks simultaneously. • Voluntary attention control. • Decision-making skills. • Events anticipation.
Transfer appropriate processing	• Increasingly difficult. • Less instructor support. • Novices training.
Error training	• Learning from errors. • Encourage effort to learn. • Freedom to experience. • Practice of complex cognitive tasks.
Self-regulation	• Self-monitoring of performance. • Comparison of progress. • Adaptability to the task demands.
Guided discovery	• System discovery on their own. • Basic training courses. • Generic simulators.
Knowledge-based training	• Deep understanding of the system. • Fault detection and correction. • Procedural skills.
Visual instruction	• Videos/visual presentations. • Visual demonstrations. • Guided reflection.

Self-regulation. Salas et al. (2012) explain that self-regulation refers to trainees' knowledge which enables them to maintain their attention on learning by self-monitoring performance, comparing their progress to the final objective, and adjusting their learning effort and methods, as required. They state that self-regulation is a way to structure training to improve learning.

Guided discovery. In this method, trainees are supposed to discover the relevant characteristics of the training task by themselves. The instructor selects the learning tasks, but the trainees have to be active and find system relationships and connections between variables and interpret them on their own (Kluge et al., 2009). It is suggested that guided discovery could be implemented in basic training courses in which generic or basic-principles simulators are used. The method is expected to help to improve the knowledge and rule acquisition of the trainees (Kluge et al., 2009).

Knowledge-based training aims to help the trainees to develop a deep understanding of the system, so that they can find and fix faults. This type of training involves learning about the interdependencies of system parameters and system boundaries (Kluge et al., 2009). The method contributes to the acquisition of procedural skills through simulator training, and it also helps the operators to sharpen their strategies and response capacity (Kluge et al., 2009).

Visual instruction refers to the use of videos or visual presentations instead of verbal instruction, which leads to observational learning (Kluge et al., 2009, Ritz et al., 2015). The method can be used to demonstrate good performance and to enable guided reflection (Ritz et al., 2015).

Refresher interventions (RI). In addition to the learning strategies mentioned above, Kluge and Frank (2014) and Salas et al. (2012) discuss the importance of refresher intervention, which aims to avoid skill decay due to long periods of non-use (Kluge and Frank, 2014). Refresher intervention involves scheduling training sessions close in time so that trainees can implement what they have learned and not lose their knowledge (Salas et al., 2012). The results of the research of Kluge and Frank (2014) show that trainees who receive refresher intervention can perform better than those who do not. They conclude that refresher intervention supports skill and knowledge retention and that it is a useful tool for mitigating skill decay (Kluge and Frank, 2014).

4.3.2 Motivation awareness

Operator simulator training is a subject that must necessarily have a human-centric perspective, given that the training is directed at people. It is therefore reasonable that a human-centric perspective takes into consideration the influence of emotions. Dorey and Knights (2015) explain that several external factors can affect the probability of trainees benefiting from simulator training. They argue that "pre-training motivation" is one of those factors, because it can influence trainees' performance and the extent to which they learn. Trainees with high motivation can benefit more from practicing on the simulator, and the higher the motivation before training the more significant the learning will be (Bell et al., 2008, Salas et al., 2012). Tichon and Diver (2010) conducted a training session where trainees operated a simulated plant while their peers watched. The final performance results were shown on a screen that the peers could also see. The authors explain that the trainees wanted to do well and to be seen to do well; they report that use of the simulator created a degree of competition among the trainees, which could be a way of motivating trainees to learn and perform better. Salas et al. (2012) claim that motivation to learn can be enhanced by giving the trainees a clear explanation of how the training content relates to learning needs, and by providing relevant training support.

5 Discussion

This literature review aimed to identify how to enable individual simulator training. To do so, a thematic analysis of the literature selected was carried out. Figure 2 shows a summary of the three central themes that were found. The results indicate that individual simulator training can be used as a supplement to on-site training. Further, prompt and real-time feedback, and end-performance assessment are necessary to enable effective individual simulator training. Finally, the development of an efficient individual simulator training setup must have a human-centric perspective. In the following, each theme will be discussed separately.

5.1 Supplement to on-site training

On-site simulator training has excellent benefits, it offers an environment that closely resembles the actual work conditions, and it allows for team training. However, the results of the literature review show that traditional on-site training practices have certain limitations. Individual simulator training can be implemented to supplement the conventional training practices and offset their weaknesses.

Training time is a significant constraint on traditional simulator training. The frequency of on-site training is once a year on average. Enabling individual simulator training would make it possible for operators to train as often as they consider necessary. They could practice specific scenarios and be able to complete all the necessary individual tasks. With individual simulator training, the frequency of training could be increased.

The number of operators who can be trained at the same time is another aspect that can be improved by individual simulator training. With individual simulator training, the number of operators who can train simultaneously will not depend on the room layout or the instructor's capabilities. This could be a significant advantage, especially in the training of novice operators, who are usually more numerous than expert operators. In fact a technical solution to this problem already exists. It has been implemented in Statoil ASA in Norway. They have a virtual simulator to which the operators have access off-site, and several operators can be connected at the same time (Nordsteien, 2015). It is not a widely used solution, however.

Further, the implementation of individual simulator training could help to assuage the great concern that currently exists in different industries about loss of knowledge due to experts' retirement. Individual simulator tools must be developed in such a way that all operators' performances are recorded and saved. This will enable a database to be created. The data should be classified so that is possible to identify the best performances, which could be used as benchmarks for feedback and the assessment of other operators. Expert operators should mainly be encouraged to perform the most relevant training tasks, so that their knowledge is saved as examples of correct performance. Their expertise and experience will thereby not be lost when they retire.

Lastly, the results of the literature review also show that individual simulator training given as pre-training could supplement the traditional simulator training practices. Individual training could be an excellent tool for developing novice operators' basic knowledge. The novice operators could train individually on general simulations to learn the basic concepts associated with specific processes and equipment. Regular operators could also use individual simulator training as a pre-training tool. They could practice tasks that help them keep their awareness of the process sharp, and refresh procedures before taking the on-site training, making the latter even more useful. Monitoring complex systems entails extensive mental demands. It can be overwhelming for operators to handle the vast amount of information that is displayed to them, especially, during abnormal or emergency situations, when they have to be more concentrated and attentive to changes in the process, and to active alarms. Hence, continuous practice is necessary to ensure that operators keep their knowledge fresh.

5.2 Feedback and assessment

The results from the literature review do not just show that individual simulator training could be a supplement to traditional training practices. They also reveal essential characteristics of simulator training that should be considered if individual simulator training is to be successful. In general, feedback and assessment are critical parameters of adequate training. Hence, both must be included in order to develop sound individual training strategies.

The literature review shows that training programs must be based on structured learning objectives. Trainees must be aware of these objectives, so that they know where special effort and attention are required during a training task. Consequently, individual simulator training must include a reasonable explanation of well-defined learning objectives. Given that trainees are on their own during individual simulator training, relevant information must be provided. This is a good example of how individual training technologies could be implemented to increase the value of individual simulator training. E-learning, LMSs, or instructional videos could be practical tools for providing a clear explanation of learning objectives.

Further, the results of the literature review indicate that a proper assessment method must be objective and repeatable; several studies suggest that the implementation of performance indicators can ensure this. Performance indicators are quantitative values that help to measure operators' performance, study the process status, and determine whether the learning objectives have been achieved. Hence, the assessment of individual simulator training must be based on appropriate performance indicators. The most representative performance indicators for the training tasks must be defined. This is especially relevant to the development of automatic feedback and automatic assessment. The automatic assessment should be presented to the operators once they have concluded the training task. The operators can thereby receive a final analysis of their performance. They can take note of their mistakes, reflect on, and learn from them. Further, an automatic assessment also enables the operators to see their improvement and their training progress.

As regards automatic, real-time feedback, this is the main characteristic required of individual simulator training. Fruitful individual training must guarantee that trainees can succeed in learning by themselves. Automatic feedback can be based on different performance indicators and other relevant process values, such as flows, temperatures, pressure, etc. Real-time monitoring of these indicators will enable prompt feedback to be given to the trainees and inform them in time about possible abnormalities in the system. The experimental results presented in Bell and Kozlowski (2002) show that adaptive guidance during simulator-based training leads to greater comprehension of the learning content. Real-time feedback can be achieved by using an ITS. Mitrovic et al. (2013) suggest that ITSs that mainly address errors could be more efficient if they are combined with positive feedback features. Using ITSs for operator training was formally proposed several years ago (Frasson and Aïmeur, 1998, Gutierrez et al., 1998, Shin and Venkatasubramanian, 1996). The current progress in technology suggests that now is an excellent moment to proceed with its implementation in practice.

In addition, automatic feedback could also be a beneficial solution for new instructors, who may feel insecure about giving feedback to their peers. If they have a tool that can help them to decide in real time what kind of feedback to offer, they may feel more confident. Moreover, this could also motivate other expert operators to become instructors. In this way, the benefits of individual simulator training are broadened, since they are also an asset for instructors.

5.3 Human-centric perspective

It is crucial to keep in mind that training technologies and methodologies are designed to be used or implemented by people. The literature review shows that simulator training can be more efficient when it takes into account the trainees' needs, such as individual learning differences or user-friendly options. Therefore, for individual simulator training to be successful, both the technical aspect and the learning aspect must be based on human-centric strategies.

Shorter non-training periods are one of the trainees' needs that must be addressed. As mentioned above, one of the main weaknesses of traditional simulator training practices is the limited time set aside for training. Therefore, trainees forget essential knowledge due to long periods of non-use. Individual simulator training is a practical solution to this issue. It can enable regular refresher exercises that can be useful for both novice and experienced operators. A common strategy for refresher interventions (RI) is Drill and Practice. Repeatedly performing a task helps to develop attention allocation and correct timing (Kluge and Frank, 2014). Kluge and Frank (2014) claim that "the effects of the Practice-RI can be attributed to a higher skill automatization, which results in a lower mental workload." Individual simulator training can be used as a refresher intervention based on drill and practice. Moreover, it can be based on any of the different learning strategies found in the literature review. Motivation is another relevant consideration in a human-centric perspective. The results from the literature review indicate that trainees' motivation is a critical issue that should be taken into account when evaluating performance. Therefore, individual simulator training must also consider trainees' motivation as an integral and effective element. Trainees' motivation to learn should be assessed before the training session, and these data should later be compared with her/his performance results. This will make it possible to study how motivation affects trainees' performance, and what kind of strategies to implement to keep them motivated.

Assessing trainees' motivation can be a complex task. There are several studies within the field of psychology and education dedicated to this issue (Noe and Schmitt, 1986, Pintrich and De Groot, 1990, Midgley et al., 2000). In the studies by Noe and Schmitt (1986), Pintrich and De Groot (1990), and Midgley et al. (2000), the authors developed self-report questionnaires that include specific items to assess trainees' motivation to learn. Trainees have to respond to these items on a Likert scale. Even though these studies are not specific to the field of simulator training, they can be used as a basis for developing a motivation assessment questionnaire that is adapted to the needs of the simulator-training field.

6 Conclusion

The aim of this article was to study how to enable individual simulator training as a supplement to traditional on-site training practices; to do so, a literature review was carried out based on a thematic analysis of literature related to the topics of simulator training, operator training, and training methodologies. Three key themes were identified: *supplement to on-site training, feedback and assessment,* and *human-centric perspective.*

The findings indicate that individual simulator training can supplement traditional simulator training practices. Individual simulator training can be used to address the weaknesses of the conventional methods, such as limited training time, the limited number of operators who can train simultaneously, or the limited availability of instructors. Further, the results also show which primary requirements individual simulator training should fulfill to be a successful practice. These primary requirements are effective automatic, real-time feedback, and automatic assessment. Moreover, individual simulator training should be based on proper learning strategies, and it should take into account operators' training motivation. Individual simulator training aims to make the operator independent of on-site training and the instructors. Thus, effective real-time feedback is one of the most critical conditions for individual simulator training being a sound and useful strategy. The conclusion is that individual simulator training should include an embedded intelligent tutoring system, which is a current, particular training solution that gives prompt and effective real-time feedback.

At the general level, individual simulator training can be seen as an always-available refresher intervention tool. Operators can at all times practice and thereby remember specific procedures. In the case of novice operators, they can rely on learning new concepts through hands-on experience of different scenarios. This research shows that there is room to integrate individual simulator training into traditional training practices. Furthermore, we conclude that individual simulator training could even help to offset the weaknesses of conventional practices.

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