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Learning transfer through industrial simulator training: Petroleum industry case

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Abstract: Efficient teamwork skills, high level of complex process knowledge and a vast set of operational abilities are essential for safe and economical operation in process industries. During the past decade, human factors have emerged as a strong research area in industrial simulator training, where traditionally focus is in the engineering technology. However, publications on the pedagogical aspects are still very few. In Norway, simulator training is one mandatory work-place training activity for process operators in the petroleum industry.

In this study, we examine the industrial simulator training practices from the pedagogical perspective of learning transfer. We ask: How do different simulator training course designs, artefacts and practices promote learning? How can the successful practices be enhanced further?

The data collection included interviews of the simulator instructors, trainees and simulator centre managers at five different simulator centres in Norway in 2012. The interview guide was organized according to the didactic categories, and the transcripts were analysed by open coding and axial coding.



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PUBLIC INTEREST STATEMENT

Major accidents in the petroleum industry, like the Texas City refinery 2005 and Deep Water Horizon at Gulf of Mexico 2011, cause environmental pollution and health problems at the communities nearby. Industrial process safety courses aim to reduce human errors which count for 70% of the accidents. This article, based on interviews, describes how simulator training methods and tools support learning transfer between process safety course and real work-place. The training scenarios are programmed in a simulator, which is a «digital twin» of the chemical process and the process control system. An experienced instructor facilitates the training course for operator teams. Effective simulator training methods improve the operator teams' hands-on skills to counteract rare events, prevent hazards and maintain economical operation. Further research will investigate instructors' competency support, operators' individual technical skills training and uniform learning assessment.

We found that the current team simulator training practices cover all the aspects of the learning design, and promote learning transfer extra ordinarily well. We suggest enhancement of the current practices by instructor competency support, individual pre-training and uniform qualitative assessment.

Subjects: Simulation & Modeling; Lifelong Learning; Work-based Learning; Educational Research; Research Methods in Education

Keywords: work-place learning; simulation-based learning; operator training simulator; learning transfer

1. Introduction and research questions

1.1. Process safety education

Safety education and training in the petroleum industry is crucial to prevent minor incidents and major accidents causing health, safety and environmental hazards. Governmental agencies in charge of the operating permits for petroleum plants set requirements for Health, Safety and Environmental (HSE) management, including mandatory safety training courses for employees and contractors (Jahn, Cook, & Graham, 2008). Efficient teamwork skills, high level of complex process knowledge and a vast set of operational abilities are essential for safe and economical operation in the petroleum industry. As automation has taken over many routine operations, organizational memory is fading along with retiring workforce. The appeal of traditional process industry workplaces is decreasing for a new generation, and continuous efforts on effective and inspiring workplace learning must be taken (Abel, 2011). Simulator training is one mandatory work-place training activity for petroleum process operators required by the Norwegian Law (Petroleum Safety Authority Norway, 2013), and high-fidelity operator training simulators (OTS) have been used for more than 30 years in the Norwegian oil and gas industry (McArdle, Cameron, & Meyer, 2010).

Educational use of simulation is a technique for organizing learning activities (Gundersen & Aareskjold, 2012), usually the teaching methods include briefing, simulation and debriefing. Simulation of work situations requires participants to experience a certain degree of realism in training setting, interacting with each other, and using artefacts relevant to application context (Aldridge & Wanless, 2012; Cant & Cooper, 2010). Central elements in simulation activities are typically linked to the use of physical models and artefacts, technical simulators, computer-based gaming technology, and/or role play among participants (Aldrich, 2005; Husebø & Rystedt, 2010; Kaakinen & Arwood, 2009; Towne, 2007). Simulation activities can be designed to mix these elements at varying degree. Different types of simulator training are used in many fields, such as aviation (Kanki, Zaal, and Kaiser 2017), education (Hodkinson, 1991; Komulainen, Enemark-Rasmussen, Sin, Fletcher, & Cameron, 2012), health care (Collin, Paloniemi, & Mecklin, 2010; Langemeyer, 2014), maritime (Øvergård, Sørensen, Hontvedt, Smit, & Nazir, 2017), nuclear industry (Skjerve & Bye, 2011) and production industries (Abel & Avery, 2012). The major drivers of simulator use in the petroleum industry are statutory requirements, safety and quality (Oppelt, Barth, & Urbas, 2015). Simulator training from a technical perspective is reviewed by Patle, Ahmad, and Rangaiah (2014) in the chemical process industries, and by Isimite, Baganz, and Hass (2018) in the biorefinery industry. A review of the process operator work and training in the chemical industry from the cognitive perspective is given by Kluge (2014).

The research and development of simulator training in the chemical process industries has traditionally focused on improving the technical functionalities and the human-machine interface of simulator software (Oppelt et al., 2015). During the past decade the “user perspective” of simulator training has received increased attention in the industry, where especially human factors have gained research focus (Glaser, 2011, Kluge, Nazir, & Manca, 2014; Nazir, Colombo, & Manca, 2013; Nazir, Kluge, & Manca, 2014; Sneesby, 2008). However, very few research results are published on the pedagogical

aspects of simulator training in the process industry (Komulainen & Sannerud, 2014a; Marcano, Haugen, Sannerud, & Komulainen, 2018; Shirley & Smidts, 2018). In this study, we will look into simulator training practices in the Norwegian oil and gas industry from a learning transfer perspective.

Simulator training has substantial impact on operators' knowledge, skills and performance. According to a quantitative survey on simulator training in the Norwegian petroleum industry (Komulainen & Sannerud, 2014b), improvement in operator effectiveness due to simulator training was 31% on average ($n = 99$). The quantitative results showed that the various categories of the didactic model (Bjørndal & Lieberg, 1978) are applied in the simulator training.

In this study, we look in to details on how industrial simulator training is conducted and how the current practices promote learning in the Norwegian petroleum industry. We examine simulator-training practices from the perspective of pedagogical theories on learning transfer and boundary crossing. Problem statement: How do various simulator training course designs, artefacts and practices promote learning? How can successful practices be enhanced further?

2. Theory on boundary crossing, learning transfer and the didactic model

2.1. Activity theory and boundary crossing

The activity theoretical fundament represents a learning theory, called “the third generation activity theory”. For example, in operator training with simulators, one can define the workplace and the training situation as two different activity systems with different purposes and in that way describe two different contexts (Engeström, 1999). The term *boundary crossing* emphasizes exploring and exploiting the differences within and between teaching and learning contexts. The conceptual framework for boundary crossing and boundary crossing objects is borrowed from socio-cultural learning theory (Engeström, 1987; Wenger, 1998). Akkerman and Bakker (2011) “define” boundary crossing as a person's interaction within and between various contexts, such as simulator training and work practice. The concept of boundary objects refers to artifacts, reifications and tools that are designed to support and mediate these boundary crossings, such as simulators, video material and learning tasks that contribute to making the simulation realistic in relation to the workplace. *Boundary crossing objects* mediate learning transfer and strengthen the interaction between theoretical teaching and practice (Henningsen & Mogensen, 2013). They consist of a medium and mechanisms that, in their own way, enable the knowledge and information to be absorbed and exchanged through personal interaction between the actors involved. These objects include:

- Interactional tools that support the participants' interaction and cooperation in practice in the training situation.
- Reflectance tools that support the participants' learning through reflection in—and about—practice (Dewey, 1996; Schön, 1995).
- Construction tools that support participants' learning through the construction and structuring of new knowledge.
- Simulation tools support participants' learning by simulating workplace practice. For example, a control room simulator.

2.2. Learning and transfer

In order to illuminate various simulator-training situations related to different work situations, we introduce the concept of transfer. It has several aspects that are of interest when it comes to the operators' different experiences, and how and what is learned in the simulator training that will be applied in practice.

The concept of transfer with a behaviouristic approach origin was introduced by Thorndike and Woodworth (1901). According to Thorndike and Woodworth (1901), transfer happens when the original learning and transfer situations have identical elements. It can be interpreted as common

landscapes and structures of physical environments or common stimulus elements (Lobato, 2006). Despite a relatively strong criticism of the classical transfer concept, like Aarkrog (2010), and Henningsen and Mogensen (2013), we choose to continue to use it. For us the traditional concept of “transfer” contains a kind of transformation, and it provides a number of perspectives to the empirical data of this article.

Traditionally, in a pedagogical context, learning transfer means transferring and using something you have learned or experienced in one situation to another situation that is somewhat different from the original situation (Aarkrog, 2010, p. 19; Haskell, 2001, p. 24; Eraut, 2004, p. 212). Transfer is a multi-faceted concept with a variety of meanings (Schunk, 2004a). Effective learning transfer is crucial to ensure the desired learning outcomes from simulator training. In the following, a short overview is given of the four types of learning transfer and boundary crossing artefacts. For a more extensive literature review on various forms of transfer, please refer to (Spetalen & Sannerud, 2013).

Close transfer is the transfer of more or less identical items between situations, contexts or practices (Tuomi-Gröhn and Engeström 2003). There are four methods of close transfer (Fogarty, Perkins, & Barell, 1992):

- Clarify expectations/learning outcomes. Make the learner aware of situations where they can apply what they learn by simulation directly in real situations, without transformation or adjustment. The instructor presents, clarifies and discusses examples with the learner.
- Compliance—overlap. Compliance/overlapping, where learners’ experience/learning is experienced almost as in a real situation.
- Simulation. Use of simulation or role play between the course participants in a similar manner as in real situation.
- Demonstration. Showing rather than simply describing and discussing. For example: the instructor demonstrates how a problem can be solved.

Remote transfer is the transfer of general knowledge and principles between situations, contexts or practices that do not necessarily seem to have much in common (Macaulay, 2000, p. 3; Perkins & Salomon, 1992; Schunk, 2004b, p. 220). Therefore, a strong link between remote transfer, boundary crossing artefacts and learning activities is important.

Forward transfer means a situation where the individual abstracts elements from the learning context and, through cognitive awareness, transmits this forward to a potential transfer context, situation, or practice (Keys & Wolfe, 1990; Schunk, 2004b). A potential for forward transfer arises when the individual is proactive and establishes connections between what happens in the learning situation and potential knowledge, practical training or learning needs in the future (Keys & Wolfe, 1990; Schunk, 2004b).

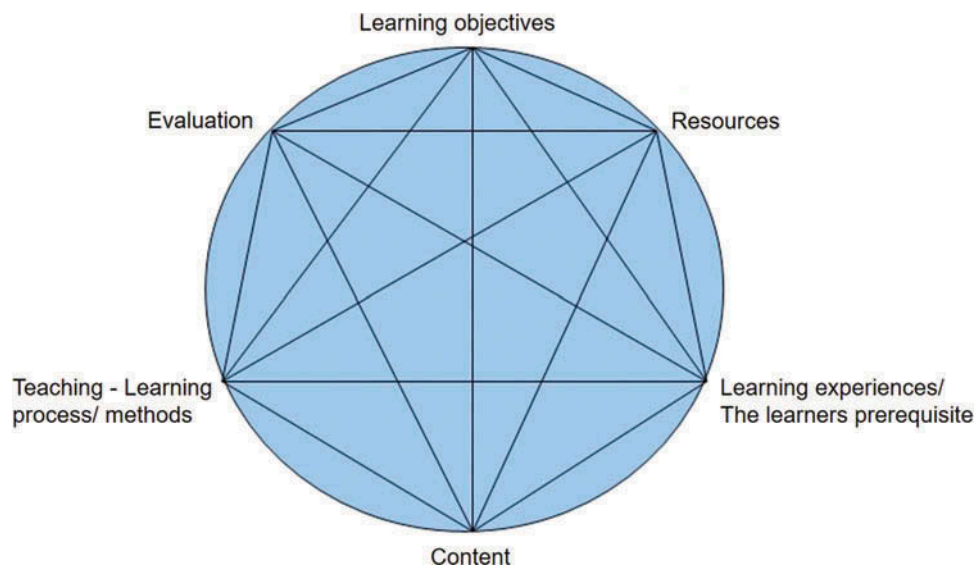
Backward transfer means that the individual abstracts conditions in practice situation, looks back, and handles today’s challenges using yesterday’s learning, practice or knowledge (Keys & Wolfe, 1990; Schunk, 2004b). An example of backward transfer is learners using previous experiences from their workplace in a learning situation that involves simulating various daily operations.

Based on the theoretical framework, the empirical data will be discussed against the concept of boundary crossing, and the concepts close transfer, remote transfer, forward transfer and backward transfer.

2.3. The didactic model

The didactic model is used as basis for the design of the simulator training courses in the simulator training centres, as described in Komulainen and Sannerud (2014a). Therefore, in this interview study, the didactic model is used as framework for the interview guide and to

Figure 1. The didactic model.



categorize the empirical data. The didactic model has six categories: learning objectives, learners' prerequisites, content, teaching methods, resources and evaluation (Bjørndal & Lieberg, 1978; Haaland & Nilsen, 2013). Category resources include instructors' prerequisites, teaching materials, room, group size and time. The model, presented in Figure 1, is a relational model in which categories are relative to each other. That means that changes made in one of the categories will also lead to changes in the other categories. The didactic model is used for design and implementation of training courses.

3. The context of the study

The context of this study is simulator training for control room process operators as part of their workplace learning. In Norway, the law requires detailed training plans for work in the control room, covering start up and normal operation procedures, changes of operating conditions, process disturbances and failures, shutdown and stops, maintenance, safety training and emergency response management (Norwegian Ministry of Labour and Social Affairs, 2011). The individual annual training plan can vary, depending on many factors, such as level of experience, operators' own wishes, availability of instructors, and company's internal requirements and practices. The length of the simulator training courses can vary from one day's re-training to a week of initial training. Most of the oil and gas facilities organize annual simulator re-training for experienced operators. (Komulainen & Sannerud, 2014a).

The instructors of simulator training sessions are typically shift leaders, very experienced operators who have participated company's internal instructor courses. The educational requirement for a control room operator trainee is 4 years of vocational education and some years of work experience as a field operator. The on-site initial training period for control room operators is usually between 1 and 2 years, and it includes on average nine days of simulator training More quantitative information on simulator training practices in Norway is provided in Komulainen and Sannerud (2014a).

Simulator training takes place in simulator room that includes the most important control room equipment, hardware, and the simulator software. The simulator software is based on mathematical models mimicking the dynamic behaviour of the petroleum processing facilities, the human-machine interface of the control system and the functionalities of the control system. The high fidelity simulator enables the creation and testing of events that would have been too dangerous or too expensive to test in the real petroleum facilities onshore and offshore.

Norway is one of 20 largest oil and gas producing countries. The Norwegian continental shelf comprises 8 onshore facilities, 78 fields, approximately 80 offshore platforms (manned and unmanned), about 50 satellite/subsea installations, and large gas- and oil transport pipeline networks (Norwegian Petroleum Directorate, 2013).

4. Materials and methods

In order to answer the research questions (page 3), we needed information and statements on experiences with specific training courses from informants representing various actors in each simulator-training centre. This approach can be considered ontologically and epistemologically something between post positivism and critical theory. Post positivism uses approaches like grounded theory with coding and analysis of data, which this study is inspired by (Heldbjerg, 1997).

We present five case examples that investigate simulator-training practices in selected simulator-training centres in the Norwegian petroleum industry. The cases include one initial training course and four different re-training courses. The first author carried out the interviews and observations during two-day long visits to each of these centres during the period April to June 2013.

We chose interview methodology based on Kvale and Brinkmann (2009), following the seven stages of an interview inquiry: thematizing, designing, interviewing, transcribing, analysing, verifying and reporting. We designed a semi-structured interview guide, presented in Table 1, to form a complete picture of simulator training. The interview guide includes a general description of the workplace, the simulator training course portfolio of the simulator centre, direct (non-participating) visual observations of the on-going simulator training and the didactic model (Bjørndal & Lieberg, 1978) of the on-going simulator training courses. The simulator centres use the didactic model for the design of each simulator course. An experienced simulator instructor, who did not participate in this study, validated the interview guide. We sent the consent form for the interviews and the semi-structured interview guide to the interviewees one week prior to the interviews. We used

Table 1. The semi-structured interview guide

Phase1	Introduction and consent
	The goal of the interview Clarification of confidentiality and anonymity issues Signing of the consent form for the interview Information about documentation of the interview (written notes)
Phase 2	General description of the workplace and simulator training courses
	General description of the process facility, the central control room and the work of the process operators. Description of the simulator courses available for trainees and experienced operators, and other simulator courses.
Phase 3	Review of the didactic model and practices of the simulator training course
	Name of the course
	Learning goals
	Course contents
	Prerequisites for the course participants
	Time, simulator room, group size
	Simulator software (main process, utility systems, DCS,...)
	Written training material, procedures, theory presentations, etc.
	Prerequisites for the instructor
	Methods for teaching and learning
	Evaluation of the learning effect during and after the simulator course
Phase 4	Summary
	Summary of the simulator training program and practices.

written notes on the interview guide as a method of recording the observations from the simulator training sessions and from the interviews with the instructors and operators. We considered the written notes to be sufficient to obtain statements about the informants' experiences of simulator training, and ultimately, to answer the research questions. Our chosen qualitative research approach does not require tape-recorded in-depth interviews like, for example, the hermeneutic approach. We sent the interview manuscripts to the interviewees in electronic format for correction one week after the interview. The interview notes were verified by the interviewees. Afterwards, we anonymized the interview notes.

The participating five onshore simulator-training centres were recruited for the study through the first author's professional simulator training network. Contact with simulator centres was established during a series of simulator seminars in Norway. There was no strategic selection of participants, but the training centre instructors and operators volunteered to participate in the study. The training centre instructors volunteered to participate in the study and invited the first author to visit their facilities during simulator training courses. The 12 respondents of the interview study were control room operators, instructors and training centre managers. The research approach's structure, procedures and implementation should be appropriate to ensure the validity and reliability of the study (Kvale & Brinkmann, 2009).

The first author, who has many years of experience with simulators and simulator training, conducted the field research. At arrival to each simulator-training centre, first, the simulator-training centre manager was interviewed about the general description of the workplace, the control room operator work and the simulator-training courses. Then, visual observations on the simulator-training room and artefacts, and the on-going simulator-training session were collected by written notes. During the breaks and after the on-going simulator training session was finished, the trainees and the instructor were interviewed about the simulator-training practices. The findings presented in this paper are based on the interview notes.

After the data collection phase was done, the verified interview manuscripts were read by both authors individually. We discussed and shared our understanding of the informants' statements about their experiences with simulator training. The second author then analyzed the manuscripts and extracted common features between the simulator training courses, learning styles, the type of simulation activities used, types of learning transfer, artefacts and boundary crossing objects that relate the training situation into real work situation.

Afterwards, both authors discussed and shared impressions on the findings. We decided to proceed through writing out the empirical data according to the didactic categories including our analysis in relation to the theoretical framework of learning transfer and boundary crossing. The fact that both researchers through a kind of research triangulation were involved in the processing and analysis of the empirical material has helped to ensure the validity of the study (Denzin & Lincoln, 2003).

Although we considered the categories in the didactic relational model as analytical categories, there was a need for processing and encoding the collected data material. The analysis work was inspired by the concepts of open coding and axial coding (Charmaz, 2014; Clarke, 2005; Corbin & Strauss, 2015). The purpose of the open coding was to identify meaningful elements that could be placed under the various didactic categories. The axial coding was primarily aimed at ensuring that relationships and facets between the different categories were identified and placed. We considered open coding and axial coding would ensure the quality of the analyses. In the further analysis, we linked empirical data to the theoretical framework of the study.

5. Results

The findings concerning the didactic models of the simulator training courses are described, and the features of learning transfer and boundary crossing objects are interpreted next. The five different simulator-training courses are described according to the didactic model. Each course description is based on the interviews with two to six informants. In the following sub-chapters,

the descriptions of simulation courses are written in normal text, while the *analysis connecting simulator-training practices to learning transfer theories is written in italics.*

5.1. Case 1: initial operator training—normal operation

The initial simulator training is a part of the overall training plan for new control room operators. It is divided into two four-day courses. The goal of the first part is to promote understanding of specific process units in the plant, and the goal of the second part is to operate the plant as a whole, and to learn about communication and operator teamwork. The initial simulator course described here is the second part of the initial simulator training.

The prerequisites for the initial simulator course participants are vocational education, minimum two years' practice as a field operator, and one year's trainee experience as control room operator. The instructor has more than 20 years' experience as a control room operator and is permanently employed as the main simulator instructor at the simulator centre.

As the simulator course is an integrated part of the trainee period, there is no exam after the simulation course, but the contents of the simulator course are included in the final exam at the end of the two-year trainee period. During the trainee period, the trainees must achieve all the learning goals defined on a detailed checklist. The instructor marks the checklist for the learning goals that were reached during the simulation course. The simulator course is registered as passed in the company's competency management database. The trainees spend four days on both simulator courses in groups of two to three. The course contents cover shutdown of the plant and start-up of process areas after a shut-down.

This simulation situation can be considered as a close transfer case, since it contributes to specific learning objectives and boundary crossing between simulator training and reality, thus making the learner more knowledgeable. Specific learning objectives give the learner a direction to focus on during the training, so that s/he achieves the expected qualifications when the training is completed.

The training methods include theory, a short briefing on each simulation scenario, the trainee working through the simulation scenario, the instructor giving feedback during the simulation scenario, and a debriefing with a review of the results after each scenario. During the simulation scenario, the instructor discusses important topics with the trainee, and relates the situations to previous courses. During the debriefing, the trainee explains and reflects on what was done in the scenario, and the instructor makes comments, corrections and suggestions for further learning and training.

All this activity, briefing, feedback during the training, and debriefing helps boundary crossing between training and reality. These activities contribute to reflection-in-action and reflection-on-action, thereby adding a reality orientation to the operator's day-to-day work (Schön, 1987, 1995). Because the instructor introduces a discussion of previous training situations, this could be a kind of backward transfer where previous experiences are used to contextualize the training.

There are two large simulator rooms containing five operator stations with two screens each, four large screens on the wall, one instructor station, one PC connected to the company's electronic document system and a printer. The DCS images and the equipment are the same as in the control room, but the room design is not the same. The simulation software includes a high-fidelity process model that is connected to the DCS replica, alarm system and ESD system. In addition the company's optimization tool, a process database and monitoring system are available in the simulator room. The written training material includes the trainee manuals, start-up and shutdown procedures, in addition to all the P&IDs, procedures, simulation scenarios, and other material that is available through the company's electronic document platform. The simulator room is not located next to the control room.

The simulator is identical to the technology in the control room and is therefore a crucial artifact in boundary crossing between training and reality. In addition, manuals and procedures are also recognizable for learners. Since the environment and the artifacts in the simulator room and the control room are very similar, we will consider the entire training situation to be close transfer, despite the fact that the instructor also uses other tools for transfer and boundary crossing.

5.2. Case 2: initial operator training—emergency situation

At this simulator-training centre, four simulator training courses are included in the two-year trainee period. The total length of the four simulator courses is 20 days, on average five days each. The first course consists of familiarization with the process and the DCS functionalities and technical systems. The second and third courses consist of normal operations, start-ups, shut-downs and typical operational problems. The training described in this sub-chapter is a simulation of a complex emergency situation that will very seldom arise in reality.

This type of training must include a variety of tools for transferring learning to reality. As the empirical data below indicate, the training includes a number of elements that, together, will be helpful for the learner in boundary crossing from training to reality.

The learning goals for the course are defined in detail: give the trainees confidence in their role as control room operators, clarify expectations of control room operators' responsibilities and tasks in emergency situations, collaboration skills in stressful situations, training in early-phase perception of threatening situations and correct responses, correct use of PA and alarm systems, develop the ability to cope with stress in the control room.

This simulation situation can be regarded as a mixture between a close transfer and a remote transfer case, although it should primarily be regarded as remote transfer. The learning objectives entail giving the learner very specific qualifications in an emergency situation. Because emergencies do not occur daily, it is particularly important that the objectives are specific and understood by the learners, so that they can envisage how to deal with a potential situation if it were to happen in reality. Completed training contributes to specific learning objectives, and the boundary crossing between simulator training and reality empowers learners in real work situations.

The course content includes emergency situations with simultaneous process disturbance and visitors in the control room. For example, an accident happens at the plant, injuring a field operator and disturbing the chemical process. Trainees are visiting in the control room, someone is reading a newspaper and another field operator calls in about a broken pump. During the course, the trainees practice effective communication and teamwork in a stressful emergency situation and the use of emergency procedures, including alarm functionalities and operational procedures.

The training methods include theory on emergency procedures, teamwork and equipment. The exercises increase in difficulty, first one emergency scenario and one process disturbance scenario, separately, and then a simultaneous emergency and process disturbance scenario. At the end of the course, the trainees take a written test, which is corrected by the instructor in collaboration with the trainee. The trainees receive feedback during the scenario if absolutely necessary, but are usually only given a team debriefing after the scenario. The exam after the fourth simulator course includes material from all the four simulator courses and consists of 40 different questions set by experienced control room operators.

This training is designed as role play in which the simulator and documentation are facilitative artifacts. Despite the training being as close to reality as possible, reality cannot be fully recreated. The instructors seem to use a rich repertoire of artifacts and circumstances that will contribute to facilitating the learners' boundary crossing to a "supposed" reality. The written test taken at the end of the training, and corrected by the instructor and the learner together, can function as a structured debriefing on "the facts" about emergencies and ensure that the learner has the requisite knowledge of

various aspects of an emergency. It is important to note that the test only tests knowledge, and not competence to manage a possible emergency.

The head of simulator training plans and organizes the simulator courses and maintains an overview of which courses the operators have completed. The simulator instructors are experienced operators who have completed the instructor training course (14 days) organized by the company.

The simulator room is situated near the control room, but the interior is not an exact replica of the control room. The simulator room consists of two parallel operator stations with three screens each, a PA and warning system, radios, a CAP panel and an instructor station. The process simulator is a high-fidelity simulator connected to the DCS and alarm systems. The simulator includes the main system and most of the utility systems. The written training material includes an emergency log form, data sheets, a checklist for PA, a telephone list, roster, list of tasks for each shift, and the operational procedures in the company's electronic document system. The simulator training is done in groups of four control room operators (two per operator station), two field operators, and one instructor. The length of the fourth simulator course is three days.

The simulator, the training materials and log books closely resemble the technology and materials in the control room. This is a crucial artifact in the boundary crossing between training and reality. This particular training targets situations that do not occur on a daily basis, and it is therefore not immediately recognizable for the learners. We will therefore regard the entire training situation as a remote transfer situation, that calls for considerable effort to achieve a high training effect. This training situation includes forward transfer as well. This is because what the participants learn can be used in a potential future application context. It is important to build cognitive bridges to potential emergency situations that are very challenging psychologically.

5.3. Case 3: annual operator re-training—uniform practice for start-up

The course described is one of the two simulator re-training courses that experienced control room operators at this site are required to take every year. This re-training course is organized with one instructor for a team of two experienced control room operators, with a maximum of four experienced operators at a time. The length of the first re-training course is three days. The course covers recent plant scenarios (such as a new start-up procedure, as described here), and control and safety. Both of the simulator courses for experienced control room operators last 3 days. The evaluation of the control and safety course is based on a written theory exam. In addition to the two simulator courses, experienced operators can choose from many different simulator courses, including emergency training with a simulator, stress management, testing of procedures, pre-defined scenarios and customized scenarios during working hours.

The contents of the first re-training course are assessed annually. Operators' wishes for additional scenarios are included. The goal of this year's re-training course was to ensure that all the control room operators start using the new, more effective start-up procedure, i.e., to ensure uniform operational practices for plant start-up. During the course, the operators start up six main process systems, including all the different procedures and sequences, in a specific order. In addition, there are some difficult operational scenarios that the operators can train in.

The learning objectives consist of a specific set of expected qualifications for a new uniform start-up practice, and they appear to be very comprehensive (six main process systems). The learners are experienced operators. We can therefore expect them to be able to understand the objectives and relate the content to their own practice. That means that the transfer process and boundary crossing to reality should be "easier". This training situation includes forward transfer as well. This is because what the participants learn will be used in a future application context. This approach can lead to ownership of their own learning in terms of their defined needs—self-directed learning.

The course starts with the instructor explaining the planned scenarios. The simulator session starts with a briefing, at which the instructor explains the new start-up method. Then, the operators run the new start-up procedure two to three times from shutdown to full production using a simulator. The course plan allows for a lot of discussion within the operator team during the simulation scenarios. The instructor gives feedback during the scenario and can help if the operator team gets stuck. Immediately after the scenario, there is a debriefing at which the team discusses and reflects on the scenario together with the instructor. The instructor gives feedback and sums up the session. There is no formal exam after the first re-training course. Completion of the course is registered in the company's competency database.

The instructor-initiated reflection in briefing, feedback during the training, and debriefing helps boundary crossing between training and reality. Reflection-in-action and reflection-on-action adds a reality orientation to the operator's day-to-day work. To contextualize the training, discussions of previous abnormal situations could be a kind of backward transfer and the discussions of possible future abnormal situations could be a kind of forward transfer.

The instructor is the head of the simulator centre and has more than 20 years of experience as an operator. For the additional customized training scenarios, every shift has one dedicated operator who can use the simulator independently. The simulator room is near the control room, and includes one large operator station for two operators, a CAP panel, and one instructor station. The software is a high-fidelity plant-specific process simulator with all the main systems and many of the utility systems. The process model is connected to the replica DCS system and the alarm system. The written training material includes a detailed report on the new start-up procedure with illustrations. All the operational procedures and handbooks are available in the company's electronic document system.

The simulator environment seems to be similar to the control room. The simulator is therefore a crucial artifact in the boundary crossing between training and reality. In addition, manuals and procedures are recognizable for learners. Even though there is a great similarity between the simulator, related manuals and reality, we will consider the whole training situation as something between close transfer and remote transfer, because the training is for something "new". This training situation also includes forward transfer because the learning will be used in a future application context.

5.4. Case 4: annual operator re-training—selected abnormal situations

At this plant, experienced operators are required to participate in 4 days of simulator training every year, 2 days in the spring and 2 days in the fall. The contents of the course are based on the wishes of the shift leader and the operators, and on scenarios the head of the training centre considers necessary. All the control room operators need to be re-certified every other year. The certification is based on a theory examination and simulation scenarios. This simulator-training centre holds simulator courses for all the experienced control room operators (4 days/year), more than 10 days of simulator training for new operators, and emergency situation management courses with simulators (2 days). The simulators are also actively used for other purposes, such as testing modifications, new logic and new procedures before they are implemented at the plant. All shifts are required to take simulator training in the new procedures. The participants are experienced control room operators.

Because learners are experienced operators, they are able to express wishes for scenarios they want to practice in. Agreeing about the need for training among operators, shift leaders and instructors can help to motivate learning and facilitate application in reality. This is a strength with respect to boundary crossings between training and reality, and can lead to ownership of the operators' own learning in terms of their defined needs—self-directed learning.

The course described here is part of the annual re-training of experienced operators. The goal of the course is to enable the operators to react to different abnormal situations in the best possible way. At the beginning of the re-training course, the instructor and the operators choose a few

scenarios from a comprehensive list of scenarios, for example, start-up of normal production after TRIP (partial shut-down due to a high-high or low-low alarm) in a process area.

Because the training is based on common perceived needs, it is possible that the objective of the training is understood and that relevant training scenarios are consciously chosen. This could be an ideal situation for transfer and boundary crossing and the application of what they have learned. This training also includes both backward and forward transfer; backward transfer because the training is also based on the operators' experience from their day-to-day work, and forward transfer because what the operators learn in the training situation can be used in future work contexts.

The training method follows the briefing-simulation-debriefing structure. First, the instructor explains the goals of the scenario, then the operator team sets the simulator to the right initial condition for the scenario. The operators and the instructor discuss what has happened prior to the TRIP and plan how to get the plant back to normal production. The operator team agrees on a plan and starts running the scenario. The instructor plays the part of the field operators, using the radio. The operators run the scenario while discussing progress in the team and monitoring the alarm log. Each scenario is about 45 min long, and is run two to three times by the operator team. At the end of the scenario, there is a debriefing session between the operator team and the instructors.

The instructor provides feedback during the scenario, especially if the operator team has difficulty solving the problem. The instructor discusses with the operators the reasons for the problems and the revised plan to bring the plant back to normal operation. The instructor also reminds the operators about product quality, explains important actions to be carried out, and answers the operators' questions by giving practical examples from the plant. The lessons learned are summarized in the debriefing session. An examination is required every other year (basis for re-certification) instead of after each session, because it is time consuming.

The instructors seem to utilize a wide repertoire of boundary objects, which ensures transfer. The instructor makes the learners aware of situations in which they can apply what they learn from the simulation directly in real situations. The instructor presents, clarifies and discusses examples with the learners. Use of simulation/role play makes the situation almost real.

The prerequisite for the instructors is long experience, a desire to become an instructor and passing the instructor course that is organized by the company. The simulator centre has two simulator-training rooms and a separate instructor room. Both of the rooms include two operator stations each with three consoles, a PC connected to the company's electronic document system, a radio and a microphone connected to the instructor room. The simulator consoles are exact replicas of those in the control room, but the room design is not the same. The instructor room includes an instructor station, a radio, and a microphone connected to the operator stations. The simulator room is not in the same building as the control room.

The simulator seems to be identical to the technology in the control room and is therefore a crucial artifact in the boundary crossing between training and reality. In addition, manuals and procedures are recognizable for learners. Even though there is a great similarity between the simulator and related manuals and the reality, we will consider the entire training situation as a mixture between a close transfer and a remote transfer case.

Each shift trains for four days a year, for two days at a time. The simulator scenarios are about 45 min long and each is run through two or three times. The group usually consists of a team of two experienced operators and one instructor. The written training material comprises paper copies of procedures and relevant process and instrumentation diagrams (P&ID). The material accessible through the company's electronic document system includes all the P&IDs, user manuals, etc. The simulation software includes a high-fidelity process simulator, a DCS system and safety system, in addition to the simulation scenario assessment tool.

5.5. Case 5: annual operator re-training—start-up/shut-down after rare events

The simulator centre serves a handful of platforms. There are three instructors with first-hand experience of the platforms and a system engineer responsible for maintenance of the simulators. The simulator centre organizes three courses for trainees and one ordinary course for experienced operators. Short extra courses can be held after process upgrades. In addition, the simulator centre buys stress management courses from an external company. The simulator course for experienced operators lasts for two days. Typically, a team of two experienced operators participate in the course organized by the instructor from their platform. The instructor has long experience as a control room operator.

The course described here is an ordinary annual simulator course for experienced operators. The goals for the course are to give operators confidence during rare events, to optimize operations, and to reduce start-up time. The operators and the instructor choose the course contents together from a list of 50 pre-made scenarios. The course consists of cases of optimal start-up after rare events and controlled shut-down (avoid trips in other parts of the platform) after rare events. The short scenarios have time constraints, which is an additional stress aspect for the operator team.

The fact that the instructors and operators agree on the training content may increase the motivation for learning, and thereby the applicability of the learning outcomes in reality. The starting point of the training is advantageous in terms of transfer and boundary crossing.

The teaching method follows the briefing-simulation-debriefing structure. After the scenario is chosen, the instructor introduces its main features. The operator team prepares a plan for the scenario, which is discussed with the instructor. The simulator is started and the operators run through the scenario. The instructor gives feedback and answers operators' questions during the scenario. There is a lot of discussion in the operator team and the more experienced operators often help the junior ones. After concluding the scenario, the operator team and the instructor discuss the whole scenario. At the debriefing session, special emphasis is placed on the difficult parts of the scenario and on reflecting on why they were tricky.

The operators receive feedback during the whole scenario and reflect on their performance afterwards at the debriefing session. There is no formal examination, but the instructor is responsible for ensuring that all the operators have reached the competency goals.

The instructors seem to use a wide repertoire of boundary objects, which ensures transfer based on reflection and communication. The various tools used are: the instructor makes the learners aware of situations where they can apply the simulation learning outcomes directly in real situations. The instructor presents, clarifies and discusses examples with the learner. The use of simulation technology and role play means it is almost like a real situation. Reflection-in-action and reflection-on-action can be appropriate activities for the boundary crossing and transfer (Schön, 1987, 1995), in other words, reflection as a boundary object. This training situation includes forward transfer as well. This is because what the participants learn can be used in a future application context.

The simulator rooms are equipped with two operator stations, one instructor station, two large screens on the front wall, and a large CAP screen. Each operator station includes three screens, a platform-specific keyboard, PA, and a PC connected to the company's electronic document system. The simulator comprises a high-fidelity model of the main processes, low-fidelity models of the utility systems, DCS replica, and the safety system. There are about 50 ready-made scenarios to choose from, and about five initial conditions to start from. The modification projects on the platforms are responsible for updating the initial conditions. The training material comprises paper copies of the relevant procedures and documents, such as the start-up procedure. All the process documentation can be accessed through the company's electronic document system.

The simulator software is almost identical to the control system interfaces and functionalities in the control room, and is therefore a crucial artefact for boundary crossing between training and

reality. In addition, manuals, procedures, and training aids are available to the learners. Since this is a generic simulator room for five different platforms, the design of the room and the control room equipment are not identical with the real control room. We will consider the entirely training situation as a mixture of a close transfer and a remote transfer case.

6. Discussion and conclusions

We will analyse further the cases and reflect the simulator training practices between the learning design, i.e. the didactic model, and the learning transfer theories, and thereby, answer our research questions.

Research Question1: How do different simulator training course designs, artefacts and practices promote learning?

Close transfer by clarification of expectations: is performed in all the cases by describing and discussing the learning goals in the beginning of the briefing session (DM: teaching method, instructor). The operator teams in collaboration with the instructor decide the simulation scenarios, like in cases 3,4 and 5; This shows deeper understanding of the learning objectives, it may increase the motivation of the operators, and thereby enforce the learning outcomes.

Close transfer by compliance and overlap between simulator training and work-practice: is present in some form in all the cases due to the simulator artefacts (DM: teaching materials). The similarity of the simulator, documents, the simulator room design and the control room equipment to the real control room creates compliance between the simulator training situation and work practice. In the normal operation case 1, the abnormal operation case 4, most the operations can be done using the plant-specific simulator and other plant-specific documents and control-room specific equipment (DM: teaching materials), and the simulation setting corresponds to close transfer. When the experienced operators (DM: learner's prerequisites, instructor) are to uniform the plant operation like in case 3 (DM: content, instructor), or they have the opportunity to choose new start-up scenarios like in case 5 (DM: content, instructor), the overlap between work situation and simulation is large (close transfer) because the context is "known" by the experienced operators (DM: learner's prerequisites).

Close transfer by instructor's demonstrations of the simulation scenarios is mainly used for novice operators, like in case1. The instructor as an expert operator (DM: instructor) showing and explaining a more complex series of operations in the simulator can help the novice operator to get better understanding of the work process than if the instructor only describes the necessary steps. Repetition and reflection (DM: teaching methods, learner's prerequisites, instructor) on the simulation scenario is very useful for the learning process of the novice operators.

Close transfer by simulation as role play: All the cases represent team scenarios where one main objective is to enhance the human factors aspects of operators' work such as team communication and management of different stressful situations. As realistic as possible role-play between the members of a shift (DM: learner's prerequisites, instructor) is really important aspect creating a link to the workplace practice, and drilling the team members with their specific tasks under different scenarios.

Remote transfer: is especially important for rare scenarios such as emergency situations (case2) that do not have much in common with normal operation. In order to enhance learning of these psychologically challenging scenarios, use of the boundary crossing objects (DM: teaching materials), close transfer by role-play (DM: learner's prerequisites, instructor) and close transfer by clarification of the learning objectives (DM: teaching methods, instructor, learner's prerequisites) are especially important. In case2, a written test (DM: evaluation) at the end of the training session can enforce the general knowledge of the rare scenarios and can support retention of theoretical knowledge. When the experienced operators (DM: learner's prerequisites) are to uniform the plant operation like in case 3 (DM:

content, instructor), or they have the opportunity to choose unseen abnormal scenarios like in cases 4 and 5 (DM:content, instructor), the new practices and events create learning by remote transfer.

Forward transfer: Team training (DM: learner's prerequisites, instructor) of the rare situations (case2), new operational practices (case3) and possible future abnormal situations (case4) and start-ups after rare events (case5) supports learning for potential future situations (DM: content). Self-directed learning with forward transfer is present in annual re-training cases 3, 4 and 5, the experienced operators (DM: learner's pre-requisites, instructor) can choose some simulation scenarios based on their upcoming needs, for example plant upgrades.

Backward transfer: in all the cases, the instructor introduces discussion on previous training and workplace situations with the trainee (DM: learner's prerequisites, teaching methods, instructor) during the simulation and debriefing, and thereby enforces learning from previous situations. Self-directed learning with backward transfer is present in annual re-training cases 3, 4 and 5; the experienced operators (DM: learner's pre-requisites, instructor) can choose some simulation scenarios based on their previous experiences in the plant.

Boundary crossing artefacts: interactional tools: in rare team scenarios (case2) the control room specific equipment (DM: teaching materials) support the trainees' interaction and cooperation in the training situation and enhance the learning of team skills.

Boundary crossing artefacts: reflectance tools: in all cases the instructors's communication with the trainees (DM: teaching method, instructor) of briefing-"feedback during simulation"-debriefing is supporting the trainees' learning through reflection in and on practice. The operator teams choosing the simulation scenarios (DM: content and learning objectives, learner's prerequisites, instructor) can be interpreted as reflective process of their work practice, like in cases 3,4 and 5, the selection of cases increases the awareness of the learning outcomes and contributes to learning transfer between simulation training and work situation.

Boundary crossing artefacts: construction tools: the plant-specific simulator, documentation and the control room specific equipment (DM: teaching materials) and the simulation scenarios (DM: content, instructor) support the trainees' construction of new knowledge in all the cases.

Boundary crossing artefacts: simulation tools: in all the cases the simulator (DM: teaching materials) is plant-specific having almost identical functionalities and dynamic responses as in the petroleum plant and has the same operator interfaces as the control system in the control room. In all the cases, the simulator room has plant-specific documents and procedures. In cases 1-4, the simulator room has control-room specific equipment. The plant-specific simulator, the plant-specific procedures and documents, and the control-room-specific equipment supports the participants learning by creating a close-to-reality training environment.

Summary

The different aspects of simulator training and their relation to the learning design (i.e. the didactic model DM) and the learning transfer methods are summarized in Table 2. The case examples of this article are all team-training scenarios. They are given in columns after column "team scenarios in general", and share all the aspects given in column "team scenarios in general". For example "normal operation scenario" and "rare event scenario" have similar elements of learning design, but differ in learning transfer methods and boundary crossing artefacts. "Normal operation scenario" uses mostly close transfer learning methods whereas "rare event scenario" uses remote and forward transfer methods and boundary crossing with construction tools.

All the aspects of the learning design and learning transfer methods are well covered in the team simulator training scenarios. The role of the instructor and the learning objectives are the most essential in most of the aspects of learning design for the simulator training sessions. Many

Table 2. Relationships between the simulator training aspects, the course design (according to the didactic model), and the learning transfer theories from the simulator-training centres

Simulator training aspects	Learning methods				Materials			Team scenarios				Evaluation		SUM	
	Selection of scenarios	Briefing	Briefing-feedback during scenarios-debriefing	Reflection on previous real/sim experiences	Plant-specific simulator, procedures, documents and equipment	Simulator room design	Case-specific equipment	Team scenarios in general	Normal operation	Abnormal operation	Uniform operation	Rare event/emergency	Instructor's feedback and trainee's reflection during and after scenario		Written test
Course design															
Learning objectives	x	x						x							3
Learner's prerequisites	x			X								x			3
Contents/scenario	x							x							2
Teaching methods		x	x	X											3
Evaluation													x	x	2
Resources:															0
Teaching materials					x		x								2
Room						x									1
Group size								x							1
Time								x							1
Instructor's Prerequisites	x	x	x	x				x					x		6
Learning transfer															
Close transfer by:															
Clarification of expectations	x	x													2
Compliance/overlap					x	x		x	x	x					5
Demonstration									x						1
Role play/simulation								x							1
Remote transfer										x	x	x		x	4
Forward transfer	x										x	x	x		4
Backward transfer	x			X									x		3
Boundary Crossing Artefacts:															
Interactional tools							x								1
Reflectance tools	x		x										x		3
Construction tools							x					x			2
Simulation tools					x										1
SUM Learning transfer	4	1	1	1	2	1	2	1	2	2	3	3	3	1	

aspects of simulator training practices contribute to close transfer. Selection of scenarios in collaboration with the trainees and instructors, continuous feedback during the scenarios, and the trainee's reflection are contributing most to promote learning transfer. We conclude that the current simulator training practices are properly designed from the learning perspective and they promote learning transfer extra ordinarily well.

Research Question 2: How can the successful practices be enhanced further?

Since the current advanced, learning promoting simulator training practices in the simulator room are covering all the aspects of learning transfer theories, learning could be enhanced further either prior or after the team simulation training sessions. We suggest three novel aspects:

- **Pre-training:** Enhance learners' prerequisites by individual training prior to team sessions: Use of individual learning prior to team training could provide more efficient use of the team training time when all the participants are prepared. Flipped class-room type of pedagogy could be suitable, as the virtual versions of the plant-specific simulators and documentation are available also outside of the control rooms. Less-complex technical scenarios, some aspects of the "new scenarios" and theoretical material could be suitable for self-training using the full-scale simulator during normal working hours. This could improve plant safety and integrity as more training can be provided for each operator. It could also bring economical savings due to improved plant-integrity (better operation) and time-efficient team training.
- **After team simulator training:** Uniform written assessment of learning would contribute to the operators qualifications (life-long learning). As our analysis shows, the instructor's feedback and team reflection during and after the simulation scenarios is really important part of the learning process and possibly this enhances also learning retention. As most of the simulator training centres do not use written exams, support for the instructors to give uniform assessment of the operator training is needed. This relates to the technical part (possibly automatic assessment) and the human factors-part (easy-to-use instructors assessment).
- **Instructor competency support:** Many experienced operators hesitate to become instructors as they feel uncomfortable to evaluate their peers and because the level of experience between the instructor and the participants can be very symmetrical, i.e. the training setting is not often an expert instructor guiding a novice trainee. Pedagogical competency support, tools and methods providing objective evaluation can possibly increase confidence of the new instructors and get more experienced operators to take the role of instructors.

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