Organizational Self-Determination and New Digital Self-Study Applications as Means for Developing Nuclear Power Plant Operation Training

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Abstract. New learning is required from nuclear power plant operators: subtle changes to work emerge as new changes to safety improvements are introduced. This study reports challenges, trade-offs and potential solutions related to career long learning in NPP operation. A NPP operating organization was studied with two focus groups sessions (N = 9). The focus group session outline was generated based on individual (N = 2) and group interviews (N = 6) along with existing published studies and concepts of learning theory. The identified challenges reflect limited resources and limited self-determination of a specific functional group as part of bigger organization.

Keywords: New learning · Nuclear power plant operation · Training development

1 Introduction

New learning and rehearsing the learnt is crucially important for nuclear power plant (NPP) operators: improvements to nuclear safety involve constant development of safety procedures and these, in turn, have to be learnt by the operators. Additionally, the operators should maintain and enhance their capability to handle challenging emergency situations, although these situations might never actualize during their career. Despite these needs, it is not at all certain that new learning is organized in the best possible fashion at power plants. Operating organizations in the NPP domain are typically large and fairly old, given the big resources needed and that the nuclear technology has been in widespread civilian use for more than half a decade already. These, along with extremely stringent safety requirements, could imply hierarchical and slowly developing organizations with limited flexibility and capability to adopt new learning trends and methods efficiently. Therefore it could beneficial to consider the current learning practices with an evaluation and perspective by an outsider, such as, a researcher, consultant, or, say, new leader. This study provides an example on how to consider and develop operator training at a NPP operating organizations. Additionally, our study findings – involving both solutions and challenges in training – may provide useful insights to other domains as well.

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The theoretical and methodological background of this study draw from the resilience engineering thinking and from the change laboratory method. Resilience engineering [1] emphasizes the positive impact of human activity as a part of a larger system in maintaining safety. This is to say that safety does not only involve the reduction of human errors (in the design of the system or during the operation), but also the problem solving capability of an active operator in special situation; no system can be considered totally safe, and eventually capable human is needed in solving or, even better, foreseeing and preventing an abnormal situation.

Our study draws inspiration from the change laboratory method [2] where development of training can be seen as a process, which firstly involves identifying the challenges the current training practices, along with the explicative background reasons to these, as well as solutions; these draw from the discussions with the workers within the organizations. In other words, change laboratory is a collaborative method: new concept for training can be identified and generated together with the operators. The change laboratory would also involve testing and establishing the new learning practices, while our study is not yet in this stage of the method.

Firstly, background understanding on training was acquired through interviewing two training developers and through two freeform interviews of operator teams; two simulator training sessions were observed as well. Based on these and background studies in NPP operation and in learning, focus group session outline was developed. Nine individuals participated in two focus group sessions.

Our study identifies a handful of practical challenges in the current learning practices and two basic sources explicating these. Firstly, it seems that the operators simply does not have sufficient time resources for optimal learning in the current work context: they would need more time to apply and more freely "play" with the simulator; this would allow better capability for handling abnormal situations. They would also need opportunities to witness and exchange the practices of operators in other shifts; this would allow the proliferation of good practices between the teams. Another basic "problem source" is being part of a hierarchical organization. This involves several aspects, such as, lack of influence on the content of learning and therefore perceived suboptimal content during learning days. Also, reflecting hierarchy and that the safety critical nature of the nuclear domain, learning the system holistically and by criticizing and inventing new practices with simulator training, can be seen as challenging due to the fact that the current safety procedures dictate operator activity very specifically. In addition to these challenges, we will also discuss preliminary solutions, that is, new training practices.

2 The Study Context: NPP Operation

Our study concerns a European NPP site; the site applies pressurized water reactors – this is typical reactor type at plants. At the studied NPP site, the operator shifts entail three types of work tasks: (1) shift supervisor (who is responsible of the overall operating activity), (2) reactor master (i.e., the primary circuit controller), and (3) turbine technician (i.e., the secondary-circuit controller). The work is in essence shift work and takes place day and night. The operators' main tasks are to monitor the NPP process and operate the plant safely and economically in all possible situations. In order to achieve this, the operators need to maintain clear understanding on state of the process. They have to be capable to act and to perform the procedures in any given time and to work in collaboration with the other staff.

Prior entering to training at the operating organization all operators have an engineering degree. The training at the plant consists of class room training, co-working and observation with the existing operators (i.e., an apprentice training), written exams, visits to the varying parts of the plant (during yearly maintenance when usually restricted areas are accessible). Fifteen work-weeks will be spent at the simulator.

After the training for new operators, the career-long new learning consists of simulator training, classroom lessons, and self-study. Any safety enhancement or other change at the plant translates into content that has to be learnt by the operators; new procedures, for example, are reviewed by the operators, as needed. The continuation training for the operators is mandatory as well, as the authorities dictate a minimum of days in simulator training.

The applied simulator is an almost exact mock-up of the operating room and, in a functional sense, it replicates the plant dynamics meticulously. The operating room and simulator consist of three walls filled with analogue controls. The control layout "replicates" power plant system itself, that is, the control devices on the walls follow the dynamics and causal links at the plant (including connections between steam lines, generators, pumps, and such). There are some newer digital devices as well, that is, computers, which are mainly used for monitoring the plant parameters; there is also one relatively newly fitted digital control device, but this too is linked to the analogue relays controlling the plant. The shift supervisor monitors the plant at the centre of the large room. One the left side operates the reactor master who controls the heat and pressure transfer, as produced by fission, at the shielded core of the plant; the turbine technician on the right, in turn, monitors and controls the heat and pressure transfer rotating a turbine connected to a generator that ultimately produces electricity.

In emergencies the plant operation relies heavily on alarms and procedures. The aim is that a procedure would be available for any given critical situation; as an alarm sets of the shift supervisor selects the corresponding procedure, that is, a specific and numbered flow-chart-filled paper leaflet. Each of the three operator types has their own dedicated procedures. During emergencies (and emergency training), a supplementary safety engineer will be asked to join the team; s/he monitors the plant state, based mainly on measures, and has her/his own set of procedures. There is, however, variation in this activity as the shifts seem to differ in the way in which they use the procedures. Some shifts have been found to express parameter-based anticipation, critical consideration of multiple sources of information, discussion and double-checking activity more than others [3]; assumedly, with dialogical interpretation of the situation, the work shifts entail better problem solving capabilities and more profound shared view of the plant state is generated [4].

Overall, NPP operation is complex and responsible work requiring career-lasting new learning. Abnormal situations are, in principle, dictated by the procedures. However, one may consider the resilience engineering thinking [1] according to which no system is complete safe and that therefore human understanding and problem solving capabilities would eventually be needed.

3 Methods

3.1 Background Studies

For background understanding, NPP's training experts and two operator teams were interviewed. Two simulator training sessions were observed as well.

The first of the training expert interviewees works as a trainer for trainers and developer at the NPP site. S/he has a long background career as a shift supervisor. The other expert informant works as a training developer and has academic training as well as vocational background in teaching and adult education. At the observer simulator training certain emergency procedures were rehearsed. After observing the training, the two shifts were interviewed in a freeform manner, in two separate sessions.

Based on these observations and interviews, as well as on literature [3, 4], basic understanding on the training and the features of the work were developed. Additionally, the first ideas of the possible challenges in training were created. This understanding was used to form the outline for two focus group sessions, which validate the findings of the background studies and provide the main data source for this study.

3.2 The Focus Group Sessions

The two focus groups consisted of the two training expert interviewees mentioned above, operator trainers, and regular NPP operators (total N = 9). Most of the participants were regular operators (N = 5).

Firstly, to provoke thinking and initiate discussion among the focus group, general challenges related to NPP training, as interpreted by the researchers, were introduced to the focus groups; these challenges were identified during the background studies (as explicated above). Firstly, a general issue found in the preliminary study was that "remembering the taught details is challenging." The issue was voiced in the after-training interviews and it reflects the complexity of procedures and the NPP system itself. Secondly, a related finding was introduced, this being the issue that "plant dynamics are not learnt as before with the simulator:" formerly the emergency procedures were much less specific, with targets rather than precise tasks. As explicated by our informants, with these more unspecific procedures, the operator had to consider the system functioning in order to actualize the procedure – this, assumedly, provided better basis for learning the system dynamics. Thirdly, it was noted that "motivation towards self-study varies strongly between the operators" – some interviewed operators expressed enthusiasm while others where less interested. Fourthly, a general observation on the curriculum was that "challenging and abnormal situations were rehearsed only seldom by the operators." Fifth, based on the literature [3] and overall observation of the work, it was concluded that NPP operation entails a general challenge of "the complexity of work and need for holistic understanding on the system."

After discussing these five potential challenges, four themes were discussed with session participants. The themes were mainly theoretically justified, but also partly derived from training expert interviews. First theme was "learning together;"

collaborative learning is a common theme in learning literature – dialogue between peers enhances exchange of good practices and new ideas, for instance [5, 6]. Second theme was called "learning goals." Prioritization between aims and the issue of who will be setting the goals was discussed here. This theme thus links to the theoretical ideas (such as constructivism) on learners being active and critical subjects (able to learning goal setting, among other things) rather than mere objects [5]. "Development of problem-solving ability" was the third theme. This connects to the resilience engineering line of research according to which safety is not merely the "negative" lack of mistakes, but also "positive" capability to solve and anticipate problems [1]. The final fourth theme was "inventing new." This is in line with the "expansive learning" [7] concept, according to which learning involves creative generation of new ideas rather than mere "input" of existing thinking.

The themes were first introduced by the researcher (the authors of this paper) and discussed with the whole focus group. Then the focus group was split into half and the participants discussed each theme without researcher participation (the operators were allowed to discuss without the trainers). The participants were guided to consider challenges and practical development ideas in view of different modes and aspects training, these being (1) simulator, (2) class room lectures, (3) self-study, and (4) evaluation: As an example, the group considered simulator-related challenges and ideas from the viewpoint of "learning together". Finally, the participants' ideas were discussed with the whole focus group and the researchers. Overall, the focus group session consisted of three types of conceptual "stimuli" for initiating discussion among the operators and their trainers: initial findings and assumptions on challenges, theoretically justified themes, and the four ways and aspects of training.

3.3 Qualitative Content Analysis

The analysis of data followed roughly the principles of basic qualitative content analysis [8], that is, the participants remarks were bundled together into fewer categories. The categories were not predefined per se, but the overall aim was to pinpoint practical training-related challenges and possible solutions. This process took place intuitively, based on perceived similarity between the participants' suggestions. The categories were generated on different levels of abstraction for the purpose of generalization of the study results: viewing the study findings more generally might help to consider whether the challenges and solutions could apply to several work contexts.

4 Results

The practical development ideas, resulting from the focus groups, reflect the challenges and problems of the current training. The ideas in Table 1 were listed after the group work sessions and they represent the possibilities and wishes that the participants considered as realistic to implement in the current training, given the current training resources and means. Of these ideas, simulator training without the dictating procedures seemed popular as this was consider to better improve understanding on the plant dynamics. Additionally, to further develop self-study was seen interesting and inspiring. The contradiction between current theory training (class room lectures) and the operators' needs for more targeted and practical learning content could be identified.

Table 1. Operators' ideas by focus group learning themes and modes of training

Focus group learning themes:	*Modes of training*:		
	Simulator	Class room lectures	Self-study
Learning together	More collaboration between shifts.	More (collaborative) hands-on exercises. Group work that enhances discussion.	Preparing for exams through collaboration in shifts. Other self-study through collaboration (e.g. transferring tacit knowledge from experts to novice).
Learning goals	More ideas from the operators included in training.		Use of digital applications (such as digital exams).
Development of problem-solving ability	"Blind" plant dynamic training without procedures. Diffusion of best practices between shifts.	More examples from real-life situations.	Development of background material for procedures.
Inventing new	More collecting needs for procedure improvements.		More self-studying new procedures and major changes in NPP before the simulator training.

Table 2 also presents results of the study, these involving now both problems and solutions, and being further categorized by the researchers. The table presents "specific sources of challenges" (second column), which entails issues that were presented at the discussion by the focus group participants or were presented by the researchers agreed upon by the participants (this taking place in one result cell "procedures now more specific than before"). The third column entails "implied practical challenges," that is, potential problems related to the abovementioned sources of challenges as assumed either by the participants or the researchers; all of these were voiced at the focus group. "Specific solutions" column (fourth column) refers to solutions discussed at focus group sessions, the solutions being voiced either by the researchers or the participants. Finally, "generic sources of challenges" and "generic solution category" (on the extreme left and right columns, respectively) are abstractions as interpreted by the researchers.

Table 2. Challenges and development solutions regarding career-long operator training at a NPP site

Generic sources of challenges	*Specific sources of challenges*	*Implied practical challenges*	*Specific solutions*	*Generic solution category*
limited resources	limited possibilities for applying simulator	limited "routine capability" in emergency situations	laptop-based simulator; another simulator	resources, new digital training applications
	limited training days	limited time for study needed issues	some less-crucial issues to self-study	resources, organizational development
	no possibilities for seeing colleagues in one's own task	lack of exchange in good work practices; lack of comparative understanding on one's own performance	new means for representing simulator performance and post-simulator self-study; simulator performance observations	resources, new digital training applications
limited self-determination of a specific functional group as part of bigger organization	the class-room training content of learning days is largely dictated top-down	lack of appropriate prioritization in content (as perceived by the operators)	some less-crucial issues to self-study (would require a special status within the whole organization)	organizational development
	limited background knowledge about procedures (at times)	limited learning by understanding and criticizing; limited bottom-up development	more resources for distributing information	resources
	procedures now more specific than before	plant dynamics not learned as before in simulator	more freeform simulator use; post-simulator self-study; laptop-based simulator	new digital training applications
	bureaucratic obstacles	reductions in the amount of training development	reconsidering some bureaucratic obstacles	organizational development

Firstly, a bundle of challenges seem to relate to the notion that there are only limited time resources available for training. The discussion recurrently reflected the issue the operators had only limited possibilities for applying simulator and limited days for training the content they felt pertinent for NPP operation. It was complained by an operator that limited simulator days do not provide sufficient experience for handling the emergency situation in "routinized manner." Simple solution would be to add more training days and, since the current simulator now seems to be well utilized, another simulator. Some additional solutions, which would not require much less dedicated training hours as provided by the energy company, emerged as well. Firstly, the idea of laptop-based "minisimulator" was discussed: apparently this had been in the making for several years now. This would allow training with the simulated plant dynamics more freely and often in self-study.

A specific problem, related to lack of training days, was that the operators lacked the possibility to witness colleagues actualizing the same task as oneself. There is rotation between teams, that is, a reactor master, for example, would not spend the whole career with the same shift leader. However, a reactor master would practically never see another reactor master in action during the career – this would only take place in the apprentice training phase. Lack of possibility to compare oneself to others implies insufficiency in both diffusion of good practices and in professional self-knowledge. There is no specific reason inhibiting this, but the training is organized in a manner such that there are in practice never opportunities for this.

Better prioritization in selecting content for training was also discussed as the means for overcoming the problems of limited time allocated for training. However, there were only limited possibilities for this, reflecting the second general problem source identified by us: limited self-determination of operators as part of the overall power company organization. Much of the content of class-room training days is dictated top-down, with issues mandatory for the whole organization. The operators generally complained that some of these mandatory-for-all issues could be transferred to self-study (as being not in the top priority, in their view) while other issues, more crucial for operation of the plant, could be studied during the learning days. For example, if the content of lectures on, say, information security, could be studied at home or during easy phases at plant – it was suggested that instead of following these lectures time could be spent, say, in visiting some parts of the plant for more profound understanding on the plant dynamics.

The subordinate nature of the operators within the hierarchical power point organization can be seen as explicative of some other issues as well. It was explained by the operators that at times they felt that sufficient background knowledge about procedures was not provided. This implies difficulties in learning by understanding and criticizing as the procedures are simply given without explication of the logics beneath the provided rules. There is also no bottom-up operator-driven development of the procedures in this approach. This varied, however, since, at times, the operators were well integrated into procedure development.

The hierarchy also relates to an issue identified in the background study and agreed upon in the focus group: emergency procedures were now much more specific than before. With the previous type of procedures, the operators could assumedly achieve more profound understanding of the plant dynamics during exceptional situations at simulator training as they had to figure out the exact operating actions by themselves. It was considered that more freeform use of simulator could be beneficial due to this. This could take place with the abovementioned laptop-based simulator. It was also discussed that developing training is generally challenging due to plant bureaucracy. We did not go much to specifics, but information security, for instance, is vigorous within the plant site and apparently a common reason for precluding developing ideas. Overall, the emerged solution options involve increasing or re-allocating time resources for training, new digital training applications and organizational development.

5 Discussion

The background studies and the focus-group sessions provided a rich set of suggestions on potential challenges and solutions (see Table 1 and Table 2). Based on these findings, we may consider potential general tensions between training and operating within an ultra-safe industry. In addition, we will also further consider solution options; self-study will be discussed in particular.

5.1 Some Learning-Related Contradictions in Ultra-Safe Industries

Bainbridge (1983) has discussed general safety-related challenges related to automation. A contradiction lies there that as the reliability of the system increases, less common will it be to experience abnormalities and problems at work – this, in turn, implies limited on-the-work learning needed for solving these situation, which could eventually lead to under-achievement in emergency situations. In other words, creating an 'ultra-safe' and highly reliably system could, in principle, create counterproductive safety results.

Similarly, creating exact foolproof procedures seems to entail an element of paradox: if the procedures can be actualized by simple rule-following, training with these procedures does not necessarily create understanding of the overall system. Simulator training would thus need to entail situations to which procedures do not exist. Actualizing simulation training of this kind might not be as simple as one might imagine: if the aim is that the system would be safe in all imagined realistic situation, creating abnormal situation to which procedures do not exist would imply a fail in the system design. Indeed, the focus group participants remarked that this kind of training takes place too seldom.

The contradictions above – that is, (1) between comprehensively dictating procedures and learning as well as (2) between the aim of absolute system safety and creation of simulator training with surprising system failures – imply challenges in cultivating problem solving capabilities. Yet, as assumed by the researchers within the resilience engineering community [1], no system can be completely safe and ultimately there may be a need for human problem solving capabilities.

5.2 Developing Self-Study

The role of self-study and self-directed learning has apparently been a recent topic of interest at the studied NPP. It could be developed by supporting collaborative learning within and between shifts, and supporting the personal and group learning goal setting. Transferring more resources for self-studying requires new organization of training and new kind of learning materials. More profoundly, it could require a mindset that supports shifting the training away from predetermined learning goals and methods. This might be a challenge in an ultra-safe context, and the development efforts should be made in close collaboration between NPP personnel and suitable stakeholders, such as learning experts and researchers.

There are many ways in which new digital possibilities could contribute to self-study as the digital laptop-based "minisimulator" could be applied by the operators as they wish. In addition to solving emergency situations and actualizing procedures, more freeform use could in principle be possible with this application, that is, the operators could more freely make their own try-outs with the programmed plant dynamics. Additionally, "gamification" is a trend in training [10], which could be of inspiration here; game elements could be introduced to the simulator use – the operators could compare "results" or they could even design tasks and emergencies one for another. This would, however, require additional programming and design.

New digital possibilities could also contribute to post-simulator self-study: automatically created representation of the performance can be imagined, this including video clips synced with time-line of simulator events; audio could be represented visually for indicating collaboration. With this kind of media representation of the simulator performance, the operators could be able to better reflect and compare activity in discussion after simulator sessions.

5.3 Limitations and Future Study Plans

A limitation of this study is certain one-sidedness: we have had the operators' opinion on training and our study entails an element of critique towards the energy company organization – some identified challenges seem to reflect inhibiting hierarchy and bureaucracy. However, a fuller understanding and alternative points of views could be achieved by discussing with representatives at higher-levels of the organizational hierarchy. We are planning to do this in the future. Additionally, reflecting the discussion above, we will also develop and test new self-study methods for further developing NPP training.

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