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Vocational learning of incident commanders in tunnel fire safety work

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Fire and rescue operations in tunnels constitute unusual and complex working environments for first responders. The ability to make correct decisions, based on the tunnel's specific characteristics, demands well-trained incident commanders equipped with sufficient knowledge and skills. The potential catastrophic consequences of tunnel fires have increasingly become a societal concern, with a growing demand to increase safety and emergency response management in European tunnels. However, from the incident commanders' perspective, learning in tunnel fire safety remains a relatively unexplored area. The current learning activities for tunnel fire response are limited and place no specific requirements on the content, instructional techniques and necessary level of competence. Designing learning activities requires careful consideration of what, why and how learning occurs. To enhance incident commanders' competence and ensure adequate emergency response during incidents in tunnels, the European Commission recently supported the development of an educational programme. As part of this programme, a pilot course was developed for incident commanders and carried out in Stavanger during the fall of 2021. The designers had a strict focus on parameters enhancing

learning, based on a vocational learning model. This article presents the design and results from the pilot course and the mechanisms that are most likely to promote and inhibit learning. Results show that learners must be engaged in activities that emphasize problem-solving abilities and critical reflection, to enhance their ability to make sense of complex situations and subsequently act effectively. Furthermore, sharing experiences requires an open atmosphere of communication and the encouragement of creativity.

***Keywords**: incident commander, tunnel fire safety, pilot course, vocational learning, competence*

Introduction

The major fires in road tunnels at the turn of the millennium (e.g., the Mont Blanc tunnel 1999, the Tauern tunnel 1999 and the St Gotthard tunnel 2001) demonstrated that tunnel fires have the potential to develop into critical events with catastrophic consequences for road tunnel users and first responders (Voeltzel & Dix, 2004). These experiences are important and influence the understanding of potential events that might also strike fire and rescue personnel responsible for emergency response in Norwegian tunnels. Even though there are 20 - 30 fires and near fires in Norwegian road tunnels annually (there are approx. 1250 tunnels in Norway), these are rarely complex or with high heat release rates. Over the last 15 years, an average of one major fire per year has occurred in Norway with the potential for becoming a major accident (more than 5 people killed). Thus, these experiences as well as potential worst-case scenarios make a range of contributions to fire and rescue personnels' ongoing learning and competence development, and they must therefore be adapted and transferred to the personnel through workplace related activities. The adaption and transfer of knowledge and experiences might be facilitated using tools that combine challenging mechanisms of tunnel fires in local tunnels, involving the relevant personnel being responsible for the emergency work.

Currently, we see worldwide that the dynamic tunnel fire safety situation places huge demands on the competence of first responders and especially on those in charge of emergency response activities. Proper tools to ensure sufficient competence enhancing works within the

emergency services are lacking. Furthermore, to our knowledge, the use of such tools in a system of didactic activities and learning processes is hardly documented in any scientific publications.

It is generally agreed that fire and rescue personnel's competence is both a universal imperative and an area of current improvement. However, it appears that the absence of tunnel fires with cascading effects and fatalities generates ambivalent attitudes amongst stakeholders, which has diminished the political community's consideration of the risks related to major tunnel fires. From the perspective of learning and competence development within the fire and rescue services, tunnel fire seems to be an underestimated phenomenon. The local fire departments are left with the responsibility for establishing adequate principles, methods and content for the tunnel fire safety learning and training of their personnel (Bjørnsen & Njå, 2019).

During the study design, we elaborated on what were the personal and collective legacies of the learning and development arising across the professional incident commanders' working lives, that we could employ in the learning process. We furthermore explored how the workplace experiences could be enhanced to achieve positive outcomes for the incident commanders in terms of their work-life capacities that are often novel and challenging involving road users and other third parties. A particular interest within this field is the concepts, practices and traditions that arise from practices themselves and how learning through occupations can best be understood and promoted (Billett, 2010).

This article aims to present the results from a pilot course developed for incident commanders involved in tunnel fire safety work and discuss the mechanisms that are most likely to promote or inhibit their ongoing learning and development. The work behind the pilot course was an integral part of the European Commission (EC) founded project (SAFEINTUNNELS) in the field of vocational education and learning aimed at enhancing fire and rescue personnels' occupational capacities and ensuring adequate performance during incidents and fires in tunnels. The project was the starting point of the normative research work reported in this article. Our major research issue was:

- How can workplace learning activities successfully be designed to enrich learning outcomes and enhance fire and rescue personnels'

competence in tunnel fire safety?

As a course developer, the first author designed the course to emphasize problem-solving abilities, critical reflective thinking and creativity focusing on incident commanders' roles and responsibilities during emergency responses in local tunnels. Effects from the pilot course are presented and discussed based on empirical data derived from participant observation, plenary evaluation, questionnaire responses and semi-structured interviews.

We employed a design science approach to adapt and transfer experiences into settings of learning processes. Design science aims to construct models, methods and implementations that are innovative and valuable (March & Smith, 1995). Principles of design science have been applied in many fields, including architecture, engineering, education, psychology and fine arts (Cross, 2001). For instance, Abrahamsson (2009) studied how methods for risk and vulnerability analysis and the evaluation of emergency responses should be constructed to prevent, mitigate and prepare for future emergencies. In the present context, a course work for incident commanders within the fire and rescue services was developed and organized for those responsible for many complex tunnels in Norway.

Design science as a premise for utilizing experiences in learning

We applied design science methodology, with the purpose of (a) supporting the design of an artefact (learning tool) to enhance incident commanders' competence in tunnel fire safety, (b) generating methodological instructions for the iterative development and evaluation of the artefact's performance, and (c) providing context-specific knowledge by reflecting on the design experiences. Thus, the scope of the design process was: *building* and *evaluating* a new artefact, where "*building is the process of constructing an artefact for a specific purpose, and evaluation is the process of determining how well the artefact performs*" (March & Smith, 1995, p. 254). In the design and development of an artefact, the designer is mainly concerned about "*how things ought to be – how they ought to be in order to attain goals and to function*" (Simon, 1996, p. 4). The interrelation between participants' experiences and how learning is achieved guided our work.

The starting point of the work was Bjørnsen et al.'s (2023) analysis of first responders' competence regarding tunnel fire safety. This analysis revealed three major dimensions in the competence domain of first responders' tunnel fire safety work: i) *emergency response and tunnel system knowledge*, ii) *practical tunnel condition knowledge*, and iii) *theoretical (physical and behavioural) knowledge*. The study results indicated that practical tunnel condition knowledge and specific knowledge of safety levels in tunnels, and how safety systems are maintained and operated is scarce amongst fire departments and first responders. When choosing response actions to combat major tunnel fire scenarios, only a few incident commanders showed situation-specific assessments and judgements that went beyond the established procedures. Further, situational uncertainties were comprehended and appraised in a variety of ways, and the first responders' understanding of which strategies and tactics should be prioritized during the different phases of the emergency response varied significantly.

Abrahamsson's (2009) process model to design science influenced our methodological approach. Figure 1 illustrates the process and differentiates between three fundamental phases: (1) development, (2) test and evaluation, and (3) results and improvements. This is an ongoing process in which improvements by enhancing competence amongst the first responding units, either being the road traffic management centre, emergency services or other entities.

Figure 1. Process for designing the course, adapted from Abrahamsson (2009)

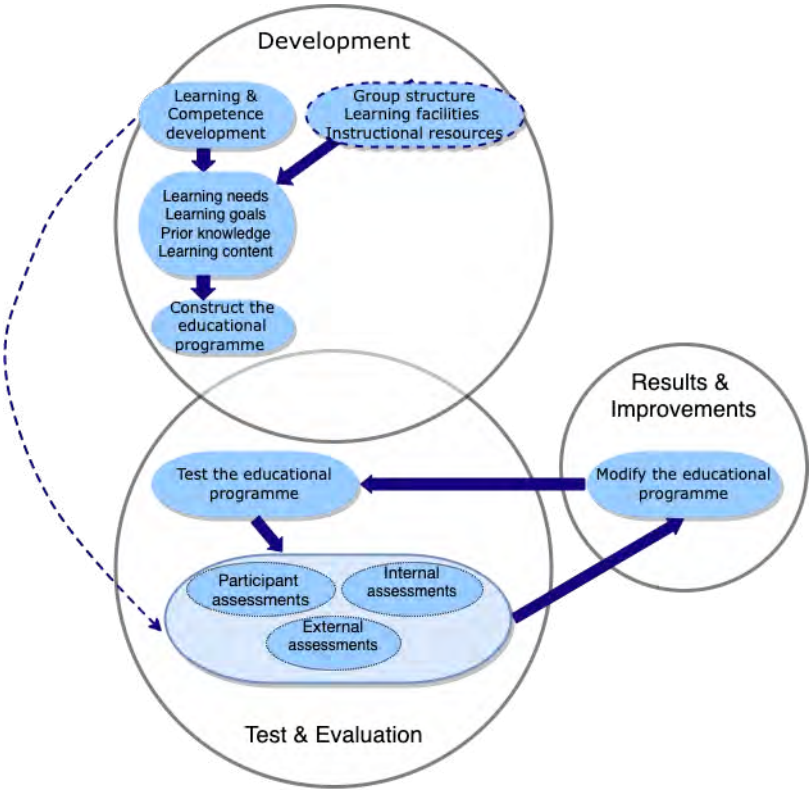

Figure 1 also structures the remainder of this paper, in which we present the learning tool we developed, and how we organised the course execution and the evaluation activities (section 2). In section 3 we provide the evaluation results and recommendations for future improvements. Further, in section 4 we provide a summary of important results.

Developing the course

Incident commanding is seen through the lens of "The seven-stage model", which is a decision-making model adopted by Norwegian fire departments for the management of emergency response situations (Mattsson & Eriksson, 2017). The seven stages emphasize: (1) assessing

the situation, (2) identifying measures, (3) establishing operational goals and tactical plan, (4) organising command scene and resources, (5) communicating and collaborating, (6) assessing available resources, and (7) evaluating effects of implemented measures. All these stages will come into play in complex tunnel fire incidents and associated responses.

The purpose of the artefact was to address learning and enhance incident commanders' competence in tunnel fire safety. We further broke this down into criteria operating the artefact (Gregor & Jones, 2007). This included comprehension of incident commanders' specific set of attributes (i.e., knowledge and skills) that they bring to the job, their experiences, the particular characteristics of the job, and the situations in which they act. We also consulted relevant research findings and their theoretical underpinnings (see Sommer et al., 2013; Bjørnsen et al., 2023; Bjørnsen et al., 2022).

Learning within the fire and rescue services involves two different processes at once: 1) an internal psychological process of acquisition and elaboration where new knowledge and information are accumulated, combined and gradually refined through critical reflective thinking, and 2) an external process of interaction and participation in work-related activities (Sommer et al., 2013; Bjørnsen et al., 2022). Hence, both socio-cultural aspects and individual cognitive aspects need to be considered to fully understand how fire and rescue personnel learn and develop competence. Sommer et al.'s (2013) model of learning in emergency response work builds on a combined approach to learning, i.e., *individual cognitive approach to learning and a socio-cultural approach to learning* and serves as a guideline for course development. In this article, we briefly introduce the learning model.

The learning model includes six interrelated elements: *contents, context, commitment, decision-making and response, reflection* and *the outcome of learning* (Sommer et al., 2013). For individuals to become professionally capable, the literature proposes that the contents of learning should comprise domain specific conceptual, procedural and dispositional knowledge (Billett, 2009). *Contents* refer to the phenomena, theories and practices being taught. Learning occurs not just in an individual's mind but in association with the context and the social groups in which they are involved and with which they identify

(Lave & Wegner, 1991). *Context* represents the social interactions and environment in which the learning activities take place. Individuals' involvement in learning activities have a strong influence on what is being learned, or if learning occurs at all (Illeris, 2010). *Commitment* relates to fire and rescue personnel's motivation and involvement in the learning activities. A further assumption is that these stimuli situations (i.e., content, context, commitment) should trigger *decision-making* and *response* in terms of mental simulations and actions in real-world contexts. *Decision-making* and *response* is associated with fire and rescue personnel's performance under the influence of contents, context and commitment in training situations. *Reflection* is widely recognized as a key element for individual learning and a powerful tool to enhance the ability to learn from experiences (Boud et. al, 1996). Lastly, the *outcome of learning* is expressed as *changes* in structures, behaviours or working methods, *confirmation* of existing knowledge and procedures/ working practices and/or *comprehension* of established practices, behaviours, etc. Recently, the model was evaluated and the relationships and interactions between its elements assessed (see Bjørnsen et al., 2022). Results provide empirical evidence confirming the explanatory power of the theoretical model in the context of learning within the fire and rescue services and demonstrate that reflection stands out as the strongest predictor for the outcome of the learning process.

The design of the course focused on instructional techniques that promote critical reflective thinking, problem-solving and creativity during the practical exercises (see Bjørnsen et al., 2022). The instructional techniques were further combined with personal experiences and constructed events (that also provide experiences). Table 1 presents the learning goals.

Table 1

Learning goals

Categories	Learning goals
Participant knows	• The tunnel's infrastructure • Implications for road users' possibilities of evacuation • Various methods to acquire situational awareness
Participant can	• Plan a safe response operation considering the tunnel's infrastructure • Implement measures that safeguard the self-rescue principle • Gather information, interpret information and anticipate the likely development of the situation
Participant masters	• Limitations and opportunities related to response operations considering the tunnel's infrastructure and characteristics of the situation • Decisions related to safe implementation of measures and tactical plan • Communication of situational awareness and tactical instructions

The type of competence required to perform adequately during emergencies varies with the complexity, the time restrictions and the expected level of interaction between first responders. Bloom's (1956) taxonomy of educational objectives was the framework for designing and organizing the learning goals. The categories are progressive sequences of educational objectives, ranging from a simple level of cognition (i.e., know), to a higher level of abstraction (i.e., master). To derive the necessary competence of incident commanders, the categories were further interpreted through Rasmussen's (1983) model of human behaviour. The model distinguishes three levels of human performance: skill-, rule- and knowledge-based. At the skill-based level, behaviour is guided by stored patterns and pre-programmed instructions that represent sensory-motor performance during activities. Rule-based behaviour is applicable during familiar situations in which solutions are oriented towards the goal and controlled by a set of rules which has proven to work successfully in previous situations. The knowledge-based behaviour is activated in unfamiliar situations when proven rules do not fit and actions must be selected using a conscious analytical process and stored knowledge. Incident command requires decision-making, problem-solving, testing solutions and generating a series of tasks and actions to cope with the situation. The primary objectives of the course (at skill, rule and knowledge behaviour levels) were directed towards developing incident commanders' capability to interpret limitations and opportunities in their working environment and implement appropriate decisions and response actions.

One aim of the course design was to engage all participants by providing relevant knowledge and experiences through a mix of theoretical lectures and practical exercises. Current learning practices have

traditionally been focused on developing personnels' basic knowledge and skills, which are essential for becoming a member of the firefighting team. However, a common belief is that theory is the preserve of the academic domain and practice that of practitioners (i.e., firefighters). The course adopts a blended learning approach integrating practice-based experience and theoretical knowledge.

To ensure theoretical anchoring and significant learning mechanisms, each of the learning model's elements was operationalized in the design of the course. The idea was that this would give opportunities for engaging in and learning new stimuli and experiences and subsequently enhance participants' work-life capacities. For instance, the theoretical lectures introduced knowledge about the tunnel's safety designs, risks and uncertainties encountered in tunnel fire responses and how different phases of emergency response should be approached by the incident commander. Further, the practical exercises consisted of scenarios of actual tunnel fire events and participants were encouraged to critically think through the consequences of their decisions and choices of action.

Testing and evaluating the course

The three-day pilot course (the artefact) was carried out in Norway during the fall of 2021. In total, eleven incident commanders, representing full-time and part-time fire departments, five instructors and two external evaluators participated. The course sessions were structured as a combination of theoretical lectures and practical exercises.

During response operations in tunnels, the incident commander is the nominated on-scene leader and is responsible for situational assessment and decision-making under time pressure and major uncertainties (e.g., number of road users inside the tunnel, traffic picture, fire substances, etc.). Their performance is therefore of utmost importance for the outcome of the emergency response. Considering that the participants were all leaders responsible for complex tunnels in their regions, the course designers expected a high degree of motivation and willingness to involve themselves in the learning activities.

For the practical exercises (i.e., role-play exercises and tabletop exercises), the participants were assigned specific roles (i.e., incident

commander and operational commander) and divided into two separate groups, consisting of five and six participants. The role-play exercises were physical and held outdoors in a training facility illustrating the context of tunnel fire responses. Further, the tabletop exercises were organized as structured discussions of tunnel fire events by using digital tools and descriptions to address scenarios' dynamics, in which the region's tunnels are based on the context. Scenarios ranged from simple incidents that slightly challenged the response capacity to complex incidents that extended beyond the local fire department's response capacity and required collaboration with the entire emergency response system.

To facilitate progress and trigger discussions during the practical exercises, each group was assisted by two instructors. The level of the instructors' involvement was to monitor responses, inject event variations and interject questions to ensure that issues critical to the exercise were discussed. To offer insight into other roles and perspectives, the participants were requested to rotate within assigned roles. The roles of incident commander and operational commander differ in responsibilities and tasks. For instance, the incident commander is responsible for strategic judgements and must organize the overall command structure for the response operation, whereas the operational commander must prioritize information gathering, communicate situational awareness and establish tactics for the response operation.

To support participants' reflections on their performance during debriefings after the role-play exercises and discussions during tabletop exercises, elements from Gibb's (1988) reflective cycle were utilized. If participants stopped discussions, the instructors prompted them into discussion with the following questions: Describe the situation and actions you engaged in. What was challenging about the situation? What sense can you make of it? What else could you have done? These questions appealed to participants' feelings, thoughts and suggestions for future actions.

The course was continuously monitored and assessed to generate modification and refinement of the artefact. Aiming to examine learning effects from the pilot course, a questionnaire was administered, and participants were requested to report their assessments of learning

outcomes (see Table 2). The questions introduced a five-point Likert scale, ranging from 1 (very small degree) to 5 (very high degree) and included:

- To what degree will the course contribute to changes in behaviour and working methods?
- To what degree has the course confirmed your knowledge, skills and practices?
- To what degree has the course contributed to deeper understanding of important issues related to tunnel fire responses?
- To what degree has the course increased your competence?

The first author also carried out semi-structured interviews to provide more comprehensive descriptions. Based on Sommer et al.'s (2013) theoretical framework for learning in emergency response work, an interview guide was developed. The indicative questions addressed the learning model's six dimensions (i.e., *contents, context, commitment, decision-making and response, reflection* and *the outcome of learning* in terms of *change, confirmation* and *comprehension*). The interviews were audio-recorded and transcribed and lasted between 32 and 55 minutes. Participation was voluntary and anonymous. All eleven incident commanders agreed to participate in the study.

Results and improvements

Through participant observation, plenary evaluation, questionnaire responses and semi-structured interviews some key findings have emerged about: 1) course execution, 2) pilot course's impact on learning outcomes, 3) learning supporting experiences, and 4) mechanisms inhibiting learning. These findings include inferences about how the process of learning was influenced by the design of the artefact.

Course execution

The first day started with theoretical lectures introducing the tunnel fire safety prevention work, the current regulations and how these affect safety systems in tunnels. The idea was to construct a knowledge basis that gives insight into the tunnel's emergency response plans and

risk assessments during tunnel fire responses. Further, two role-play exercises conducted in real-time settings, in the field, with operational personnel executing their functions and using relevant equipment were carried out. These exercises were designed to demonstrate difficulties in executing response strategies and tactics. During these exercises, we observed that critical cues and uncertainties were uncovered and clarified unsystematically within the firefighting team while the incident developed and some participants had trouble performing at the expected standard level and maintaining control over the situation. Triggered by the exercise-related factors, these participants were exposed to a variety of emotional challenges, which later influenced their learning.

On the second and third day of the course, participants were gradually introduced to new reinforcements, in terms of more theoretical lectures and tabletop exercises. The current learning activities seem to underestimate the value of reflection and the participants are usually taught a certain pattern of actions for responding to simulated events during training exercises. To stimulate critical reflective thinking and engage in problem-solving, tabletop scenarios were typically formulated as narratives of potential tunnel fire events that progressively increased in complexity. The scenarios unfolded in well-known tunnels and encompassed authentic situational descriptions that challenged the participants to utilize their existing knowledge to explore and think creatively and construct new knowledge and skills for responding to the presented events.

Pilot course's impact on learning outcomes

To capture the effects of the pilot course on participants' learning outcomes and competence development, a questionnaire was administered. In general, participants reported great efficacy of the learning experiences for each measurement scale. The greatest effects were found for comprehension and competence development. Table 2 summarizes the answers collected through this questionnaire.

Table 2

Assessments of learning outcomes and competence (N=11)

Item	Assessments
Changes in behaviour and working methods	Moderate degree = 1; High degree = 4; Very high degree = 6
Confirmation of existing knowledge and practices	Moderate degree = 1; High degree = 5; Very high degree = 5
Comprehension of tunnel fire response practices	High degree = 4; Very high degree = 7
Increased competence in tunnel fire safety	High degree = 3; Very high degree = 8

These measures delineate factors that are directly linked to the outcome of learning. However, the interviews provided insight into participants' learning experiences beyond the assessments reported in the questionnaire. During the interviews, participants expressed changes in mindset, experiences and working methods. A common feature emphasized by participants was an increased awareness of the complexity that tunnel fires represent and the importance of having sufficient knowledge of the tunnels in their field of responsibility. Some reported that becoming acquainted with the contents of the tunnel's emergency response plans was a main priority when they returned to work. Others conveyed that the course triggered their interest in searching for additional knowledge to further develop their repertoire of response actions and decision-making skills. As one participant said: "The course has increased my awareness that we have several tunnels at risk in our district and that I have to be better prepared to be able to deal with incidents when they occur. I can't continue hoping that incidents won't occur on my watch."

Since all participants lacked experience with major tunnel fires, it seems that the tabletop exercises provided new experiences of relevant aspects and phenomena that should be considered during response operations. For example, concerns were addressed regarding the predefined ventilation strategy and road users' behaviour. As one participant expressed: "Inflicting smoke on people and expecting them to evacuate long distances uphill is a hopeless scenario. This would be a crisis for us. One needs to possess knowledge to dare to go against the fixed protocols; hopefully, after such a course, some of the incident commanders will dare to do so." Participants also expressed thoughtful consideration regarding interagency collaboration to investigate the type and severity of the incident and formulate an appropriate response. The role of the Road Traffic Centre (RTC) was particularly pointed to as essential for facilitating information gathering and acquiring situational awareness. Changes in working methods were described in terms of

more active involvement with the other emergency response services to gather risk critical information for establishing operational priorities and ensuring the availability of resources in the earliest phase of the response.

Expressions of confirmation were associated with the participants' existing knowledge and the fire department's response practices. Discussing collective response actions and which aspects of the situation are most significant was regarded as highly valuable for confirming that the situation was interpreted correctly and that appropriate actions were prioritized. The majority described the practical exercises as confirming their work practices and ways of thinking. Perhaps most importantly, the group agreed that the "The seven-stage model" offers an appropriate methodology for the management of tunnel fire response operations. Nevertheless, many regarded the model as theoretical and stated that a thorough presentation of its methodology would have been beneficial before the execution of the role-play exercises.

Other expressions of confirmation were related to new insights emerging from the theoretical lectures and discussions during the tabletop exercises. These insights served as a kind of positive reinforcement of the participant's existing knowledge. For instance, it was well known that response operations in tunnels represent a high-risk working environment for fire and rescue personnel. New appreciations were uncovered in terms of the durability of breathing air, access to extinguishing agents, as well as the risk connected to rockslide and back-layering during firefighting operations.

Comprehension was related to a deeper understanding of tunnel fire phenomena and insights into how road users' behaviour may affect the response operation. For example, in the event of a tunnel fire, the tunnel's emergency response plans require road traffic operators to launch radio instructions for safe and prompt evacuation. Some participants stated that, depending on road users' location in the tunnel and the tunnel's design, different evacuation behaviour is needed and the information may be ambiguous. They explained that, in single bore bi-directional tunnels, the information conveyed should contain a clear message to avoid road users who have passed the fire scene turning their vehicles and getting trapped in smoke. Similarly, in twin bore unidirectional tunnels, the information should prevent road users from

turning their vehicles and hindering access to the emergency response services. Generally, the more participants knew about such aspects in different kinds of situations, the better prepared they felt to face potential events. As one participant said: "The course has given me more detailed knowledge about the tunnel's construction, the implications related to road users' behaviour and the importance of collaboration with road traffic operators. Now, I feel better equipped and more in control of issues that we might face. Through automating some actions, capacity is liberated to focus on specific aspects of the situation, which otherwise wouldn't have been captured."

Learning-supporting experiences from the pilot course

A common feature was that the contents of the learning activities provided knowledge and experiences relevant to the incident commander role. While the theoretical lectures introduced facts, principles and concepts, the practical exercises were situated in the local context of the fire department, that is, adapted to the specific challenges that participants may encounter in tunnel fires. The assessments revealed that the local knowledge emphasis was of great value and offered authentic opportunities to engage in decision-making and response actions. The participants agreed that solving realistic problems in well-known tunnels helped to visualize the situation and enhanced their understanding of how different choices of action (i.e., choice of access route, allocation of resources, location of command scene) can influence the outcome of an incident.

An important prerequisite for learning was adequate participation motivation. Results suggest that the motivational condition was met and that participants were motivated to learn because they considered the learning activities highly relevant to their occupational tasks. Some were relatively new in the role of incident commander and enthusiastic to be part of a project for vocational education in tunnel fire safety. As one participant explained: "It's only a question of time before a major incident occurs in our tunnels, and now I feel more comfortable with the thought of experiencing such an event. Instead of entering the situation with uncertainty, I will be more committed, trusting my knowledge and capability to stand my ground."

A fundamental factor promoting involvement in learning activities was a

high level of trust between participants and instructors. When selecting instructors, the designers assumed that, while external instructors might possess more didactic skills, internal instructors would better understand the needs of the group and promote a safe forum for discussions. During the interviews, participants described a non-threatening learning environment, with no risk of embarrassment or interpersonal discomfort when collectively discussing choices of action to solve specific problems. Since they all knew each other and there were no "real" consequences for making mistakes or saying something inappropriate, they felt that the discussions allowed creativity and the testing of different solutions.

The use of the training facility and relevant equipment during the role-play exercises made it possible to achieve realistic challenges, and participants experienced the context of learning as similar to real-world situations. For instance, the command scene was established at some distance from the tunnel's portal and the incident commander did not have direct visibility of the incident scene or face-to-face dialogue with the operational commander. The exercises were designed so that communication and exchange of information were only allowed through radio devices. Results demonstrated that participants faced high workloads and communication challenges, as well as difficulties with the command handover, transfer of information and the achievement of common situational awareness. Moreover, incorrect use of radio operating frequencies, difficulty in managing information overload and the necessity for leader support were identified. Participants highlighted the need for leader support and argued that they cannot perform at the expected level of quality without assistance. One participant described always being alone in the vehicle on the way to an incident, and that, in this phase, they too often become preoccupied with the execution of less significant tasks (i.e., handling radio devices, localization and navigation).

Mechanisms inhibiting learning and recommendations for further improvement

In general, the amount of subject knowledge taught was considered appropriate. However, some participants reported that they would have preferred more theoretical knowledge about how to approach tunnel fire situations before the execution of the role-play exercises. Within

the current design of the course, the transition from instruction in the classroom to execution of physical role-play exercises was considered too abrupt. To provide a better foundation for engaging in practical exercises, the revised version of the course should also introduce a systematic review of "The seven-stage model", preferably with exemplifications of how the methodology can be incorporated into the current response practices.

Tunnel fire responses are normally joint-effort work, involving several emergency response services (i.e., fire, health, police, road traffic and emergency operators). Responding to major tunnel fires requires this variety of actors to work together and share knowledge, often outside their familiar structures. This part of the response and the interagency collaboration were not captured in the design of the course. In all instances, contacts and communication with other emergency response services were simulated by instructors. Thus, opportunities to test the collaboration and communication between the various agencies were not provided. The assessments emphasized that collaboration across agencies is an important issue that needs to be incorporated into the future design of the course. This will offer opportunities to test communication, exchange experiences, increase shared knowledge of plans and procedures, and identify potentially different understandings of responsibilities. As one participant said: "It is implicit in the design of the course that the involved actors understand and use our terminology and communication means and provide correct information. Often in real-life situations, none of these things work. The course should reveal important disconnects and differences in interpretations. Otherwise, we train under the wrong premises." To improve the design of the course and enhance the quality of learning, representatives from the tunnel emergency response system should be invited to participate in the course.

Learning is a continuous process that extends beyond the context in which the knowledge is initially learnt. However, it is not obvious how the participants will integrate the learning outcomes into their vocational practices. As the major aim of the course is to lead to improvements in work situations (i.e., tunnel fire responses) and enhance incident commanders' competence, the revised design should provide time and space to discuss the application of learning outcomes in the current work practices.

Reflecting on the learning experiences through discussions was an important aspect accounted for in the design of the course. Results indicate that tabletop exercises can be powerful tools for learning if appropriate attention is given to incorporating cognitive processes and pedagogical principles into their design and structure. To stimulate reflection, it is not sufficient to simply get participants to discuss choices of actions to the scenarios' challenges. The course should create conditions that enable participants to make inquiries about the assumptions and understandings that form their decisions and response actions. To support this, focused attention needs to be placed on instructors' competencies. The fire and rescue services have not established any specific requirements to ensure pedagogical competence amongst instructors. The current practice for selecting instructors is based on practical experience and personal interest related to the subject area to be taught. Our work indicates the need to develop pedagogical competence and equip instructors with methods and tools that promote problem-solving, critical reflective thinking and creativity.

Considering that each tunnel has its own characteristics, and fire and rescue services differ in terms of organization, resources and practices, how the learning content is structured and organized should be rooted in the needs of the local fire department. Thus, we recognize the limits of the course's generalisability across other countries. Most of the theoretical lectures, including "The seven-stage model", are more or less applicable to other contexts. However, the practical exercises were situated in the local context of the fire department where the pilot course was conducted. To account for potential applicability to other countries, the practical exercises should emphasize the situational needs of the fire department and the specific characteristics of the tunnels in the fire department's geographical area. Situational needs should also influence the development of learning goals with subsequent considerations, thus making the implementation of a standardized curriculum nearly impossible.

Conclusion

In this study, we examined how principles of design science and elements of Sommer et al.'s (2013) model of learning in emergency response work may be combined to develop an artefact that facilitates learning and enhances incident commanders' competence in tunnel

fire safety. The findings described above point to ways that the fire and rescue services can refine their existing approach to learning and integrate a new one to enhance workplace learning and achieve positive outcomes for the personnel in terms of improved work-life capacities.

As expected, in line with Sommer et al.'s (2013) model of learning, much learning seems to arise through participants' engagement in the learning activities. This engagement in goal-directed activities stimulates the process of ongoing development, and participants are exposed to new experiences and challenges from which new learning arises. However, the quality of learning is supported by the specific information (i.e., content of learning) provided by the artefact, the context where learning takes place, the instructional techniques and interactions with more experienced others (i.e., colleagues and instructors). The design of the course has assisted these interactions through the assignment of specific roles during the practical exercises, solving specific problems, and guided instruction. We claim that these kinds of interactions provide knowledge and experiences that might otherwise be limited by participants' discovery alone. As instructing can be quite demanding and to help embed significant mechanisms and foundational principles for learning in learning activities, greater consideration needs to be directed towards preparing the instructors for their roles.

To enhance the actual level of knowledge within the fire department and to meet the needs of incident commanders, the course placed a large emphasis on specific emergency response knowledge in local tunnel contexts. This knowledge was previously revealed to be scarce (Bjørnsen et al., 2023). Incident commanders' capability to successfully cope with tunnel fire responses is neither acquired fully in the classroom nor learned entirely through experiences in the field. Tabletop exercises in combination with theoretical lectures and physical role-play exercises seem to be useful means for the vocational learning of incident commanders, as they bridge the gap between classroom instruction in the abstract and practical training, by allowing participants to apply their knowledge and experiences to carefully chosen scenarios. Importantly to note is that these exercises are effective only when they are accompanied by techniques that stimulate critical reflection and by skilled instructors. Thus, the practical exercises were designed to encourage the participants to exchange experiences and critically reflect upon how their decisions and choices of action may affect the outcome

of the response operation. The use of critical reflection and creativity to solve realistic problems in local tunnel contexts seems to be a new approach for fire and rescue services.

The model of learning in emergency response work has assisted the development of the course and was originally developed by several researchers who gathered information from a wide range of sources which contributes positively to the trustworthiness of the findings. However, the practical contribution of the course was tested in the context of one specific fire department which is acknowledged as well-informed and highly competent in tunnel fire safety. Future studies might benefit from testing the course in a broader context and further investigate how the learning-supporting experiences revealed in this study relate to other fire and rescue services to improve performances in tunnel fire responses.

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