Chapter 3
Tracing Outcomes of Learning from Errors on the Level of Knowledge

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Introduction

At most weddings, a professional photographer is hired to capture the celebratory moments of the carefully planned and long awaited event. Especially during the church ceremony, it is crucial that some moments are shot nicely, e.g., when the bride and groom exchange the wedding rings. This means that the photographer mostly operates very close to the bridal couple and is therefore inside the area on which the attention of the whole wedding party is centred. For this reason, the photographer's dress needs to be somewhat festive during such an occasion. Inexperienced photographers often make typical mistakes when dressing to shoot a marriage. Firstly, it is important to wear clothes that are not hindering in terms of freedom of movement: the photographer may have to kneel down or climb onto a small stool in order to quickly bring the camera into promising positions and angles. Thereby, a long or rather tight skirt is very disadvantageous. In addition, slippery or high-heeled shoes are a 'no go'. Secondly, a photographer exhibiting underwear in front of a wedding party when kneeling down around the bridal couple to get a good shot is disturbing for a wedding ceremony. Therefore, the photographer should take care not to wear too tight or too short clothes which tend to slip easily.[1]

Imagine an inexperienced photographer making one of the above-described 'rookie mistakes' when shooting a wedding. When the photographer hears about the

[1] This example is a summary of an informal conversation between the first author of this chapter and a professional photographer.

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error—maybe through a subsequent complaint by the client—it is too late to do something about what happened. The situation has already passed; it can only be hoped that the mistake has no further harmful effects. A proximate question is: Why should precious time and energy be invested in pondering an event which itself is already over? This question is even more salient, as thinking about one's own errors may be time consuming and possibly connected with unpleasant insights into one's own fallibility.

The obvious—albeit not trivial—answer to this question is as follows: The primary motivation to concern oneself with one's own errors is to improve skills and knowledge in ways which allow for the future avoidance of the same or of similar errors (Barach & Small, 2000). With regard to research on learning from errors, this chapter argues that it is important to focus more strongly on the outcomes brought about by error-related learning. Thus, the first assumption of this chapter is as follows:

(i) *Researching outcomes of error-related learning is a sensible and necessary, but hitherto widely neglected, perspective.*
Drawing upon educational theorisation, the example discussed above can basically be described as a glimpse into a photographer's experiential knowledge (Waibel, 2002). Various contributions to the ongoing discourse around workplace learning (Billett, 2001a, 2001b; Boud & Gerrick, 1999; Gruber & Palonen, 2007; Harteis & Billett, 2008; Smith, 2003; Stenström & Tynjälä, 2009) have conceptualised employees' experiential knowledge as an important source of their professional competence (e.g., Eraut, 2000). As will be shown in this chapter, various interrelationships between the experience of errors and experiential knowledge are plausible: Experiential knowledge may result from error-related learning and may be a helpful basis for not repeating errors. Moreover, existing experiential knowledge may also influence any future (error-related) learning processes.

One interesting aspect about the initial example is that it involves rather specific recommendations about how a photographer should *not* dress while shooting a wedding ceremony. These may be very valuable for a professional photographer, because they pinpoint certain mistakes and hence allow for their purposeful avoidance. This assumption relates to the concept of negative knowledge (Gartmeier, Bauer, Gruber, & Heid, 2008; Minsky, 1994; Oser & Spychiger, 2005; Parviainen & Eriksson, 2006). Negative knowledge is focused on what not to do in a certain situation, on what assumptions are wrong with regard to a certain problem or on limitations in one's own or somebody else's skills or knowledge. As will be shown here, this concept offers a promising way to conceptualise and research outcomes of error-related learning. This point foreshadows the present chapter's second key assumption:

(ii) *The theory of negative knowledge represents a promising perspective for researching outcomes of error-related learning.*
A critical issue related to negative knowledge can again be exemplified by drawing upon the initial example: A photographer may become aware about how *not* to dress when shooting a wedding. However, this insight may leave

open the question of which clothes to actually choose when doing so. In other words, negative knowledge may be helpful for avoiding mistakes. In some situations, however, it may provide little information about how to actually solve a given problem. This has conceptual and methodological consequences which future studies on knowledge as an outcome of error-related learning should consider: Two main points are, firstly, to pay attention to the embeddedness of negative knowledge in more general structures of experiential knowledge, and secondly, to use research methods which allow for obtaining more information on the process of constructing knowledge from an encountered (error) episode. This relates to the third point this chapter seeks to make:

(iii) *Future studies on knowledge as an outcome of error-related learning processes should seek to shed light on the embeddedness of negative knowledge in structures of experiential knowledge.*

The present chapter's line of argument follows the three key points advanced in this introductory section. In addressing some 'blind spots' of existing research on learning from errors, we outline the need to put a stronger focus on researching its outcomes in general. We will introduce the theory of negative knowledge as a recent theoretical approach engaging in this perspective, and outline challenges for research on this issue. In this way, we draw conclusions on future inquiries concerning negative knowledge as an outcome of learning from errors.

Processes, Prerequisites and Outcomes of Learning from Errors

A body of literature has evolved over the past years which focuses on the investigation of learning from errors in professional contexts (for an overview, see Bauer & Mulder, 2008). These works share the basic conjecture that errors at work, although being adverse events, bear significant potential for professional learning and innovation. Beyond their agreement upon this basic assumption, we argue that scholars have hitherto mainly analysed error-related learning processes from two different perspectives, focusing on prerequisites of such learning as well as on the learning process itself:

(1) The initiation and success of error-related learning processes depend upon individual and social variables, which can hence be regarded as prerequisites of such learning (Bauer, 2008). Individual-level variables assumed to influence how employees cope with occurring errors were introduced by Rybowiak, Garst, Frese, and Batinic (1999). Under the label *error-orientation*, the authors focus on different individual beliefs related to errors at work. Error-competence, for example, addresses the extent to which individuals believe in being able to cope with errors they are faced with at their workplace. Another facet, error-anticipation, addresses employees' expectation that errors will happen from time to time. One central assumption pursued by Rybowiak et al. is that

individuals who are persuaded of their ability to resolve upcoming problems or to thereby learn important things will more likely be able to cope effectively with error situations. In terms of sociocultural prerequisites for learning from errors, Edmondson (2004) has found team climate variables, namely the degree to which errors are openly discussed in a work-group, to be influential for employees' ability to identify and resolve mistakes and problems at work.

(2) In addition to these prerequisites, researchers have focused on error-related learning processes, which may involve both individual and social activities. Authors adopting this perspective research the efficacy of different activities in which individuals engage after an error at work has happened. Typical goals of such activities are cause analysis and the development of alternative action strategies (Bauer & Mulder, 2008). Therefore, reflective activities in particular have been identified as crucial (Van Woerkom, 2003). Due to the fact that errors at work are frequently described as potentially hazardous and hence stressful events (Perrow, 1984), activities taken up after an error has occurred might furthermore range from intentional ignorance to covering up errors (Rybowiak et al., 1999). On the social level, different error-related learning activities were described by Bauer and Mulder (2007), including the exchange of experiences, seeking advice from more experienced colleagues or root cause analysis in conversation with the supervisor.

Both introduced perspectives are important for understanding error-related learning processes at work. However, they still only provide an incomplete picture of the phenomenon. We hypothesise a third research perspective to be crucial: the perspective of outcomes of error-related learning processes, especially those occurring at the cognitive level.

What Can Be Learnt from Errors? Existing Results and Open Questions

The importance of the outcome-perspective can be substantiated in two different ways: firstly, in terms of its value for better explaining the results of existing studies, and secondly, through its potential for closing gaps in existing research on learning from errors.

Outcomes of learning from errors are traced in two recent studies. In a cross-sectional study conducted in two European countries, organisational error-management culture was found to be positively interrelated with performance measures of the organisations under investigation (Van Dyck, Frese, Baer, & Sonnentag, 2005). To explain these results, the authors argue that a more error-friendly organisational culture may, e.g., foster error-related communication, experimentation and innovativeness—all of which are plausible facilitative factors with regard to company performance. However, the "quantitative findings do not reveal the precise mechanisms by which error management culture translates into better performance" (Van Dyck et al., 2005, p. 1237).

In the latter respect, another study is interesting, as it investigated the effects of an innovative approach to skills training. In *error management training* (Frese et al., 1991), trainees autonomously work on challenging tasks—which makes the frequent occurrence of errors during the training process probable. In order to improve the trainees' skills for coping with errors and to prevent frustration, the trainees are instructed in how to learn from errors. Moreover, they are informed about the positive effects that making errors and learning from them may have on the learning processes as a whole (Keith & Frese, 2008). Different studies show that error management training—in certain respects—leads to better training outcomes than error-avoidance training (e.g., Chillarege, Nordstrom, & Williams, 2003; Nordstrom, Wendland, & Williams, 1998). For the heuristic task at hand, the most relevant study on error-management training (Keith & Frese, 2005) investigates psychological mechanisms responsible for its superiority compared to error-avoidance training. Error management training positively influences participants' emotional control, as well as their metacognitive skills. Both of these self-regulatory processes were shown to be significantly related to training outcomes.

In the reported studies' results, the different conclusions are similar: Not only does learning from errors have a significant impact on performance measures, both on the individual and on higher-order levels, but these effects can also be traced according to the level of individuals' cognitive processes, offering a plausible explanation for improvements in performance.

The reported results on self-regulatory mechanisms do not provide a sufficient explanation for how individuals profit from error-related learning. We argue that knowledge concepts have an increased explanatory power in this respect. To substantiate this claim, we subsequently outline three different challenges for research on learning from errors which make the necessity to trace its outcomes on the level of knowledge plausible. Engaging in this perspective allows for explaining employees' ability to anticipate errors, shedding light on how lessons learned from errors are transferred into future practice, and researching potentially counter-productive effects of learning from errors.

Knowledge-Based Error Anticipation

Research on learning from errors mainly focuses on employees' reactions to errors which have occurred in their professional practice. Von Weizsäcker and von Weizsäcker (1984) state that the handling of episodes which deviate from the usual course of things is not limited to just reacting to errors taking place. Beyond that, knowledge about possible errors can play an important role when making up plans about how to solve a task at hand. Similarly, Rybowiak et al. (1999) argue that the ability of employees to anticipate errors is an important cornerstone of their performance. If errors are anticipated, they may be avoided entirely or better coped with when they do occur. Different explanations may account for an employee recognising an error's leading signs, having a gut feeling or other ways of anticipating

errors. One proximate approach is that earlier, error-related learning experiences have given an employee the opportunity to construct knowledge which entails experience-based error anticipation. This has two important consequences.

Firstly, from this perspective, anticipated errors can also be opportunities for learning from errors. It is an open question in which way the processes and surrounding conditions are different in the case of learning through error-anticipation. However, it can be said that here, thorough reflection and proactive planning of problem-solving strategies, and especially their limitations, there seem to be crucial prerequisites for identifying possible error-sources and for acting accordingly. In this respect, it is especially interesting to focus on proactive behaviours such as personal initiative (Frese & Fay, 2001), as these aim at tackling errors and problems before they occur and have a negative impact.

Secondly, it seems plausible that error-anticipation strongly depends upon an employee having had earlier error-related learning experiences. These may allow for the construction of specialised knowledge which, e.g., entails an employee's raised awareness about situations that bear a high risk of errors taking place. Yet, it is not understood that learning from errors fosters an individual's error-anticipative capacity. In this respect, the next point might be significant.

Transfer of Lessons Learned from Errors

As mentioned above, the interest of educational researchers in learning from errors currently focuses strongly on actions and action strategies carried out after an error has occurred, as well as on relevant surrounding conditions. As a legitimation of this interest, scholars assume that learning from errors entails valuable results which positively influence the competence of professionals or the design of work processes (Edmondson, 2004; Hofmann & Stetzer, 1998). From this point of view, research on learning from errors mainly focuses on actions or action strategies taken up after an error has occurred, but draws its legitimacy from the long-term beneficial effects of such learning.

The latter, in turn, has not yet been thoroughly studied in research on learning from errors. Doing so would mean focusing on results of learning from errors, which go beyond things like the mere correction of the error or the removal of possible damage induced by the incident. Questions relating to this perspective are what results learning from errors yields and how these are transferred to other situations. Key concepts in research on transfer are near versus far, as well as positive versus negative transfer (Yamnill & McLean, 2001). With regard to the quality of error-related learning processes, a possibly interesting measure could be whether resulting learning outcomes can only be transferred to very similar situations or if far transfer is also possible, because, e.g., a thorough analysis leads to deeper insights into an error's genealogy. Focusing on the positive/negative distinction, it might be asked whether certain error-related learning experiences, e.g., being assigned blame for an error one does not feel responsible for, impede learning from other, similar situations—this would be a case of negative transfer. This aspect is also discussed below.

Counter-Productivity of the Results of Learning from Errors

On the one hand, researchers draw upon the assumption that learning from errors contributes to improving employees' competence and companies' productivity. On the other hand, scholars have argued that certain lessons may be learned from errors which—from the perspective of personal and organisational development—have to be described as being adverse: Error-related experiences may lead to employees showing defensive behaviour, like covering up errors or avoiding the development of innovative problem-solving strategies (Rybowiak et al., 1999; Van Dyck et al., 2005). Other, different approaches are also relevant at this point: firstly, the concept of *defensive routines* (Argyris, 1986a). This concept focuses organisational habits which aim at the avoidance of critical and open discourses and which are counterproductive with regard to innovation and organisational learning. Secondly, the idea of employees' showing 'skilled incompetence' (Argyris, 1986b; Holmer, 2001) assumes that skills and knowledge can also be used for achieving undesirable or counterproductive learning outcomes. One such outcome of learning from errors may be knowledge about how best to cover up one's own mistakes or to embellish inadequate work results successfully. The described concepts relate to what Schüttelkopf (2008) conceptualises as *regressive*—as opposed to *progressive*—learning from errors. A case of regressive learning from errors would occur when employees decide to reduce or withdraw their participation in situations which they perceive as being error critical, e.g., team meetings or open discussions with supervisors. In contrast, the idea of progressive learning from errors focuses on innovative strategies of error-avoidance, e.g., an active search for better problem-solving approaches or a purposeful modification of existing work processes.

The points made in this section can be regarded as challenges for research on learning from errors. In order to meet these challenges, we argue that it is promising to focus the outcomes of error-related learning on the level of individuals' knowledge. By means of knowledge concepts, employees' ability to anticipate errors can be explained. Moreover, knowledge can be transferred and applied to similar situations and may be used in ways which are not in line with a company's 'official' policies. With regard to the goal of better understanding outcomes of learning from errors on the level of knowledge, the aforementioned theory of negative knowledge is interesting. This theoretical approach will be illustrated more fully in the next section.

Negative Knowledge as an Outcome of Learning from Errors

From the initial episodic example in the photography context, a recommendation can be drawn which seems valuable for a professional photographer: *When shooting a wedding, avoid wearing clothes that overly hinder your movements or that tend to slip unwantedly!* This is a typical example of negative knowledge (Gartmeier et al., 2008; Minsky, 1994; Oser & Spychiger, 2005; Parviainen & Eriksson, 2006). Theoretical and empirical evidence suggest the plausibility of assuming negative

knowledge to be an outcome of experiencing and learning from errors. Below, we will delineate the theoretical background of this concept. On this basis, some limitations of the approach will be discussed and used to develop perspectives for future research.

Theoretical Conception

Drawing upon existing approaches, the following, workplace-specific definition of negative knowledge is proposed:

> Negative knowledge is context- and task-specific experiential knowledge which contains insights into assumptions which are wrong, but tend to be considered right. Typically, negative knowledge is acquired through experiencing and learning from (others' or own) workplace errors, because such learning reveals wrong assumptions being pursued. As it comprises insights into instances and causes of bad practice, the relevance of negative knowledge lies in assisting an actor in developing better practices and thereby avoiding error repetition.

This definition integrates existing conceptions of negative knowledge which will be introduced below. In particular, we focus Oser's (1996) work in the context of moral education and Minsky's (1994) ideas on negative expertise used.

With his concept of negative moral knowledge, Oser (1996) pursues the assumption that a person's experience and knowledge about immoral behaviour, for example about stealing, can play an important role in the future prevention of this behaviour. This is because knowledge about what not to do may serve as a contrastive element to the 'right' behaviour. In other words, *knowledge* about what should not be done is conceptualised as an outcome of actually *doing* something wrong and experiencing unpleasant consequences. For example, imagine a child stealing something and being caught by his or her parents: The subsequent lecture the parents give makes the child feel guilty and ashamed about the wrongdoing. In the concept of negative moral knowledge, such a negative experience as a consequence of wrong behaviour is hypothesised to possess an emotionally impressive momentum which is a crucial aspect of the intention not to repeat the experience. In that sense, the statement 'You shall not steal!' may on its own not be a very effective imperative. However, it gains a higher level of relevance if understood as an essential part of the establishment of moral categories like 'right' and 'wrong' through processes of experiential learning.

Pursuing a similar idea, Minsky (1994) states that experts in a professional field "must know both how to achieve goals and how to avoid disasters" (p. 13). It is assumed that—besides taking positive measures—the primary way to avoid accidents is by avoiding actions that are known to cause trouble. Minsky makes two main points: firstly, a negative way to conceptualise expertise is to regard experts as persons who are able to deliberately avoid errors, and secondly, one plausible prerequisite of this ability is experts' negative knowledge. According to Minsky, negative knowledge can be conceived as a metacognitive resource helping to monitor

action at work by reminding the actor of what to avoid. To further illustrate the concept of negative knowledge, we will briefly sketch how its acquisition, cognitive representation and application are conceptualised.

Acquisition of Negative Knowledge

Although educational settings can teach what should be avoided in the performance of a task, personal experience is potentially more powerful in the acquisition of negative knowledge (Oser & Spychiger, 2005). Hence, negative knowledge is basically a special form of experiential knowledge that is acquired through processes of learning from experience (Kolb, 1984). An experience may serve as a starting point for the acquisition of negative knowledge, especially in cases which raise an actor's awareness of having wrong assumptions or applying wrong strategies for solving a problem at hand. Typically, errors at work are seen as experiences that meet this description (Gartmeier et al., 2008). Errors are conceptualised as a category of adverse events that produce "stress, accidents, inefficient human-machine interaction, quality and performance problems, and a bad climate" (Rybowiak et al., 1999, p. 528). Nevertheless, errors provide opportunities to reflect on their causes and thereby gain insights that may allow for the avoidance of similar errors in future practice. While conducting error-related learning activities, professionals may become aware of having inadequate conceptions, such as lacking particular problem-solving strategies (Bauer, 2008; van Woerkom, 2003). The results of such reflective processes contribute to building a body of negative knowledge about what should be avoided in a given class of work situations.

Representation of Negative Knowledge

The concept of negative knowledge can be subsumed under more general conceptions of knowledge representation typically used in research on experts' knowledge. In particular, script theories have been useful for modelling the representation of experts' action-oriented knowledge (Schank, 1999). Scripts are generalised action schemata which guide action in specific situations (e.g., the typical sequence of actions when visiting a restaurant) and which may comprise elements of declarative as well as procedural knowledge (Anderson & Lebiere, 1998). Scripts may change dynamically with the experience of new episodes. An important script modification practice is the integration of deviant episodes into existing scripts (Kolodner, 1983; Schank, 1999). Hence, learning from errors can be interpreted as a process of extending an existing script with instances where its application was unsuccessful, and with possible explanations for this deviance (Bauer, 2008). These extensions may assist professional action in future, similar situations by reminding the actor of the failed episode, possible explanations for the failure and

alternative ways of acting. As has been suggested above, the idea of negative knowledge fits neatly into the theory of scripts as a more comprehensive framework to represent action-oriented knowledge. One could conceive of negative knowledge as represented in those parts of scripts that refer to conditions which would probably cause failures in task attainment.

Application of Negative Knowledge

Negative knowledge has a valuable problem-solving function in specific task situations because it reminds employees of potential error sources and is therefore valuable to avoid errors (Oser & Spychiger, 2005). The advantage of having negative knowledge may be summarised in the popular idiom 'forewarned is forearmed'. Being aware of what things can go wrong when working on a certain task is a plausible precondition for being able to purposefully avoid these errors (Oser & Spychiger, 2005). We assume that professionals in any given domain have a situation-specific repertoire of negative rules that makes them anticipate particular errors and is thus helpful for the avoidance of errors (Gartmeier et al., 2008; Kolodner, 1983; Minsky, 1994). Being aware of what actions are inappropriate in a given context is useful to ensure successful action, especially in situations that carry a fair chance of making errors or in which doing something wrong may result in serious consequences (Reason, 1990). This assumption is consistent with arguments from research on case-based reasoning showing that analogies from cases experienced earlier are helpful when it comes to mastering subsequent, similar situations (Kolodner, 1983). An example from the domain of chess illustrates the propositions made above: A chess rule of thumb says, 'A knight on the rim is grim.' This rule explicitly tells a player not to move a knight into a disadvantageous position where it has limited influence on the game. Although novice players may easily learn this rule, understanding its implications and the underlying rationale requires deeper insight into the game. Nevertheless, in representing an experienced player's knowledge, this simple formula may be helpful for inexperienced players as a guideline preventing them from getting into a disadvantageous position. In other words, in adhering to the exemplified rule and in seeking to understand the rationale behind it, a player is encouraged to anticipate possible negative consequences of a certain move.

This idea is also relevant for workplace contexts, because to "reduce disruptions, employees need to be able to sense problems and act proactively about them before they occur" (Baer & Frese, 2003, p. 46). The concept of negative knowledge offers a plausible explanation for this ability: Along with growing professional practice, an employee accumulates experience in handling errors. As the condensed result of such experiences, negative knowledge represents generalised guidelines for practice that make an employee aware of possible or, especially, typical errors for a particular task. Knowing what not to do in order to avoid such errors is an important precondition for acting in proactive and error-preventative ways.

We argue that negative knowledge provides a promising approach with regard to researching outcomes of error-related learning. Yet, researching employees' negative knowledge is a challenging task, especially due to two issues: firstly, the formal restrictedness of negative knowledge, and secondly, its primary focus on avoiding actions or disqualifying assumptions. These issues will be discussed below.

Challenges for Research on Negative Knowledge

To make the first point, it may sometimes be difficult to unambiguously identify negative knowledge in verbal data. For instance, the initially exemplified photographer could verbalise negative knowledge in stating, 'If you're dressing to shoot a wedding, take care not to wear unpractical clothes'. Yet, the photographer could also make the very same point in saying, e.g., 'If you're shooting a wedding, take care to wear clothes in which you can move easily'. The former exemplified statement would meet the definition of negative knowledge, whereas the latter would not.

This poses a challenge for research upon negative knowledge which is connected to the formal restrictedness of this concept. Firstly, participants in a study on negative knowledge might deliberately formulate certain statements in a negative way so that the relative importance of negative knowledge is overestimated. Secondly, it is possible that employees express knowledge which they see as being very relevant and helpful for avoiding errors and which is strongly connected to error experiences, but which does not meet the idea of negative knowledge, being focused on what is wrong. It has been argued that the negative knowledge approach provides a way to research the knowledge-based aspect of employees' error-avoidance capacity (Gartmeier et al., 2008). Yet, it can also be assumed that not all employees' error-related knowledge is necessarily negative knowledge. Future studies should hence seek to achieve a more complete picture of which type of knowledge employees use to avoid errors. Among other issues, this challenge will be addressed in the final section of the present chapter.

The second challenge for research on negative knowledge lies in this approach yielding a very plausible explanation for not acting incompetently, but offers no immediate explanation for competent behaviour.

Given the assumption that "the things we do not do far outnumber the things that we do" (Tykocinski & Pittman, 1998, p. 607), the value of negative knowledge might be estimated to be very high. This also ties in with other sources: Minsky (1994) assumes that a large part of expertise—as we can observe it, e.g., in the performance of an experienced professional—is actually negative expertise; i.e., the effect of cognitive agencies which deliberately focus on avoiding things like detours or inefficiencies, asking the wrong questions and making mistakes. Pursing a similar idea, Oser (1996) advances the hypothesis that half of aeroplane pilots' professional competence is built on negative knowledge because, "especially in situations of danger, the pilot alone must be able to perform without the slightest failure"

(Oser, 1996, p. 69). Interestingly, this quotation stresses the importance of negative knowledge, but at the same time highlights a limitation of the concept: In order to perform competently, problems have to be solved by actually *doing* the right things at the right time—not by avoiding actions. One aspect which many definitions of professionals' competence draw upon is their capacity to solve problems at work (Weinert, 2001); yet, the theory of negative knowledge offers only an indirect explanation of how problems are actually solved.

Here, the differentiation advanced above between regressive and progressive learning from errors (Schüttelkopf, 2008) comes into play: As was argued, negative knowledge is focused upon what *not* to do. Hence, such knowledge is useful as a basis for innovative behaviour only to the extent that it allows for avoiding errors which have occurred earlier. This means that the concept of negative knowledge provides an explanation for *regressive* learning from errors, i.e., for avoiding erroneous behaviour. Yet, it offers only an indirect explanation for *progressive* learning from errors, i.e., for using errors as starting points for the development of innovations. Entirely focusing upon the avoidance of problems does not tie in with the notion of modern work environments requesting employees to be dynamic and innovative, show personal initiative (Frese & Fay, 2001) and adapt quickly to workplace changes that occur (Bauer & Gruber, 2007). In such situations, doing nothing may even be the worst of all possible mistakes.

To sum up, it is our position that researching outcomes of learning from errors is worthwhile and that knowledge concepts provide a valuable basis for doing so. One open question is how future studies can research knowledge-based results of error-related learning and thereby deal with the challenges discussed above. This question will be discussed in the following section.

Researching Employees' Error-Related Knowledge: Conceptual and Methodological Conclusions

As the main difference between Einstein and an amoeba, Popper (1972) identifies Einstein's quality to purposefully strive for the avoidance of errors. In the present chapter, it has been argued that one resource which may be helpful for Einstein in his ambition to avoid errors is specialised knowledge resulting from experiencing and learning from errors. In this chapter's final section, we will firstly discuss the relationship between employees' experiential and negative knowledge. We will then draw conceptual conclusions which may be valuable for future studies on these issues.

Negative knowledge allows for avoiding actions which are known to yield poor outcomes (Gartmeier et al., 2008; Oser & Spychiger, 2005). Yet, to actually solve a problem, it may sometimes not suffice to have relevant negative knowledge. This may be the case for two reasons: After eliminating wrong ways to solve a given problem based on negative knowledge, either *several* plausible ways or *no* plausible problem-solving strategy may remain. We hence argue that it is important to research

negative knowledge in its embeddedness in structures of error-related, experiential knowledge (Staw & Barsade, 1993).

This is plausible, as experiencing and learning from an error may allow an employee to gain insights into a large variety of aspects connected to the episode. Insights may be gained, e.g., into an error's enabling conditions and its immediate consequences within the work environment. Moreover, an employee may learn about things to be done to resolve the problem: own feelings or personal and social resources to cope with errors (Meurier, 2000). Briefly stated, errors can be eminently rich learning experiences; as incidents of failed practice, they are not merely opportunities to develop negative knowledge. Experiencing an error episode allows for the acquisition of a wider repertoire of very specific and differentiated experiential knowledge (Van Woerkom, 2003).

The importance of experiential knowledge as an outcome of error-related learning is apparent in the literature from different disciplines. For instance, a study conducted in the medical context raises the question of whether blogs are useful tools for improving the extent to which health care professionals collect and share medical error knowledge (Swain, 2007, p. 303). The quoted author does not further define or specify her theoretical reference point concerning knowledge. Yet, the concept of experiential knowledge is implicitly addressed in the cited contribution. It is hence in line with other studies that stress the organisational relevance of preserving employees' error-related, experiential knowledge (Barach & Small, 2000; Dovey & Phillips, 2004; Uribe, Schweikhart, Pathak, & Marsh, 2002).

The previously mentioned study on the effects of companies' error management culture (Van Dyck et al., 2005) is also relevant here. The authors argue that a positive error management culture "encompasses organisational practices related to communicating about errors, to sharing error knowledge, to helping in error situations, and to quickly detecting and handling errors" (Van Dyck et al., 2005, p. 1229). Speaking of *error knowledge*, the authors describe a form of knowledge which is informally shared and negotiated. This ties in well with established concepts of experiential knowledge: Such knowledge is formed during the process of performing the very actions for which it is helpful. Briefly stated, experiential knowledge is action-oriented knowledge structured in ways which are convenient for solving common problems at work (Gruber, 1999).

One central aspect of error episodes is that they are often experienced as being stressful and difficult (Bauer, 2008). This is an optimal precondition for the establishment of experiential knowledge: Scholars stress that such knowledge is often constructed from experiences which are personally meaningful and challenging (Kolb, 1984). An actor's experiential knowledge may incorporate information about the whole process of experiencing and learning from an error. In contrast, negative knowledge rather represents quintessences drawn from such a learning process—like in the initial photography example: The exemplified negative knowledge '*Don't wear too tight clothes when shooting a wedding*' is a general rule which could also appear in a practically oriented guidebook for professional photographers. Our assumption here is that experiential knowledge can have a descriptive, but also a rule-like, character, whereas negative knowledge most often has a

rule-like, stronger quintessential character. For understanding why a (positive or negative) rule is relevant, it is necessary to gain insight into the contextual conditions under which it has been established or is applied. Hence, for fully understanding the relevance of negative knowledge, its embeddedness into structures of experiential knowledge needs to be researched.

We assume negative knowledge to be inextricably entangled within structures of experiential knowledge. In other words, negative knowledge represents an aspect of experiential knowledge which expresses a genuine characteristic of error-related learning, i.e., the effort to learn something in order to prevent the same (or reasonably similar) incidents from happening in the future.

From what has so far been advanced in this section, three conclusions for future studies on employees' knowledge as an outcome of learning from errors are put forward: (1) negative knowledge should be researched in its embeddedness in structures of experiential knowledge; (2) future studies should make use of a combination of knowledge-analytical methods and direct observations in realistic tasks; and (3) longitudinal research designs should be applied to research the evolvement of employees' error-related knowledge:

Consider the Embeddedness of Negative Knowledge in Structures of Experiential Knowledge

Future studies should apply knowledge elicitation techniques which allow the respondents to give insights into contextual and episodic reference points of their knowledge. This means that semi-structured or explorative techniques lend themselves to this application, e.g., the critical incident technique (Flanagan, 1954; Norman, Redfern, Tomalin, & Oliver, 1992). In this way, the interviewer possesses enough degrees of freedom to pose targeted questions which aim at shedding light on how error-related knowledge is acquired and the influence of relevant contextual elements.

Another relevant approach would be to conduct longitudinal studies with a repeated measurement of selected subjects' error-specific, experiential knowledge. Such an approach is particularly promising during phases of professional life when vocational experience is collected within a new or a radically changed work environment. In the sense of an initially peripheral (Billett, 2001a; Lave & Wenger, 1991), yet centre-oriented participation, it is plausible that in these cases the development of expertise depends upon a continued accumulation of workplace-specific knowledge through a large number of micro-learning processes. These reflect how the new professional environment and its challenges are tackled.

The research techniques described would allow to be shed light on how employees come from the experience of a concrete incident to hypotheses and insights into how the incident came about, its effects and consequences, ways to limit its harmfulness and its future avoidance. On this episodic basis, various more abstract components of employees' error-related knowledge may be theorised: Generalising over a larger number of error episodes, an employee may acquire

knowledge about typical sources of errors and about which different forms of errors occur in the respective work environment. Moreover, it seems helpful to know about how best to discover errors—maybe there are certain points in work processes which offer better opportunities to install control routines than others. Then, employees may have knowledge about what can best be done in the case of different errors or in finding out which colleague may offer helpful support in the case of certain error situations.

Consider the Embeddedness of Error-Related Knowledge in a Particular Sociocultural Context

In most cases, an error is related to the (partial) frustration of certain human intentions or expectations (Rasmussen, 1987). This means that whether something is judged as being an error or not does not depend only on attributes of the phenomenon itself. Instead, such judgments are delivered with reference to certain normative criteria: For example, when shooting a wedding, the primary and most important criterion for the photographer is to satisfy the wishes of the customer. To achieve this primary goal, various other criteria have to be adhered to, e.g., technical or aesthetic criteria.

In general, these criteria reflect (implicit or explicit) rules and practices which pertain to a certain (work-)context (Bauer, 2008; Heid, 1999). As argued above, negative knowledge is strongly related to experiencing and learning from errors at work. Hence, to fully understand the rationale behind negative knowledge, it is very helpful to also gain insights into the conditions relevant in the particular context in which it is researched.

As was advanced, the sentence ‘Don’t wear too tight clothes when shooting a wedding!’ represents a photographer’s negative knowledge. To fully appreciate the relevance of this statement, understanding several contextual aspects is helpful. Firstly, as was described above, the photographer’s primary goal is to satisfy the customer. This goal would be missed if the customer’s wedding party is upset. Secondly, it is helpful to understand why this goal is relevant in the first place: Of course, a photographer who does not manage to satisfy customers might have trouble surviving economically.

From exemplifying these criteria, we conclude that, when researching employees’ error-related knowledge, it is illuminative to systematically research the local, contextual conditions of the respondents’ work environment. In that way, the situatedness of knowledge in a particular sociocultural context can be taken into account. This means that individual and organisational knowledge is constructed inside a framework which incorporates and reflects local practices of sense-making. The mutual relationships between local conditions prevalent at a certain workplace and different individuals’ error-related experiential knowledge may reveal interesting differences between individual patterns of sense-making (Billett, 2001a; Waibel, 2002).

Comparatively Focus on Two Ways to Externalise Knowledge: Verbalisation and Application in Practical Tasks

A lucky person may solve a problem correctly without really being able to tell how the success came about. On the other hand, a problem may be solved by means of very purposefully planning and carrying out a certain course of actions. For this differentiation, Heid (1996) has coined the terms trivial and nontrivial competence. Now, one interesting aspect about the application of negative knowledge is that it results in *not* doing something. Applying this differentiation, it is apparent that it makes a big difference whether a person performs without making errors just because of being lucky or because of purposefully avoiding disadvantageous ways to act. However, what somebody does *not* do only appears in behaviour if the person *verbalises* the decision to avoid a certain actions. Hence, in order to differentiate between acts of trivial and nontrivial competence, future studies should make use of a combination of knowledge-analytic methods and direct observation techniques in realistic tasks (Gruber, 1999; Rothe & Schindler, 1996).

This could resolve the problem described above connected to the formal restrictedness of negative knowledge. In this context, it was argued that the identification of negative knowledge depends upon possible incidental variations in formulation. The essential idea of the theory of negative knowledge is that being aware of wrong assumptions is valuable because it may be helpful for not acting wrongly or committing errors. Yet, how can this awareness be captured?

Above, we argued that a respondent may formulate a statement in a negative way. Vice versa, a respondent could also possess negative knowledge, but formulate statements in a positive way. Hence, several questions remain open: Is an actor aware of certain possible mistakes when performing a certain task? Is an actor aware of the wrong assumptions or wrong actions which lead to these mistakes? As suggested, these questions could be answered by combining knowledge elicitation techniques with performance measures obtained in challenging tasks.

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