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# FEHLER

Ihre Funktionen im Kontext individueller
und gesellschaftlicher Entwicklung

# ERRORS

Their Functions in Context of Individual
and Societal Development

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# Learning from errors: Process and contextual conditions

## Towards a model of individual processes within contexts

## 1 Introduction

Learning processes naturally involve making errors. Reciprocally, errors contain seeds of learning – provided that learners are able to deal with their errors in an adaptive and reflexive manner. According to the literature on the role of errors in learning and instruction, different theoretical perspectives and empirical approaches have been adopted so far: From a historical point of view within the behaviouristic tradition, Skinner (1968) argued for an error prevention approach by learning solely through positive reinforcement. In the field of cognitive psychology, it was assumed that erroneous or misleading information would interfere with correct information and thus hinder the recall of correct answers (Ayers & Reder, 1998). In contrast, contemporary research provides a theoretical framework as well as empirical evidence that overcoming impasses and the reflection on errors and misconceptions are important for learning progress since they help to establish accurate mental models (Kapur, 2008; Keith & Frese, 2005; Oser & Spychiger, 2005; Siegler, 2002; VanLehn, Siler, Murray, Yamauchi, & Baggett, 2003). Many studies focused on learning from erroneous examples (Fiori & Zuccheri, 2005; Große & Renkl, 2007), but only a few studies considered the learning opportunities that learners' own errors may provide. For instance, Mathan and Koedinger (2005) emphasised the beneficial potential of errors in computer-based tutor systems. Based on the concept of "productive failure" (Kapur, 2008), Westermann and Rummel (2012) found that delaying instruction (including metacognitive support during collaborative grappling with the learning contents and with wrong solution attempts) leads to better learning outcomes. However, these studies and their theoretical background neither addressed individual reactions following errors in a narrower sense, nor did they address the motivational *processes* involved in learning from errors.

Learning from one's own error(s) requires the maintenance of task-engagement in order to analyse and to correct the error at hand, and to reflect about the underlying misconceptions. Therefore, motivational and emotional processes conducive to learning from errors are necessary (pre-) conditions after the detection of an error. However, learners react differently in the face of errors. To explain why some learners show adaptive affective and motivational reactions and learning gains after errors whereas some do not, several individual and contextual factors as well as self-regulation processes must be taken into account. Subsequent (and parallel) to emotional

and motivational processes, individual reactions further comprise cognitive and behavioural reactions which are specifically adjusted to the error in question (Dresel, Schober, Ziegler, Grassinger, & Steuer, 2013; Tulis, Grassinger, & Dresel, 2011). It can be assumed that more stable individual beliefs and orientations, and contextual factors, such as supportive versus negative reactions by the teacher or classmates, have an impact on these individual error reactions.

The aim of the present chapter is to summarise these conditions and processes that are specific for individuals' learning from errors. Based on this review, we propose a model to explain in particular how individual learners – influenced by individual traits and situational/contextual factors – deal with errors when they are involved in learning processes. Within this framework, we further intend to explain how emotional, motivational and self-regulative processes interact after the perception of an error by integrating parts of other models, such as primary and secondary appraisals (Lazarus, 1991, 1993), feedback loops (Carver & Scheier, 1998) and self-regulatory learning processes (Boekaerts, 2006, 2010; Winne & Hadwin, 1998). Findings from studies on error management (Heimbeck, Frese, Sonnentag, & Keith, 2003; Mindnich, Wuttke, & Seifried, 2008) finalise the proposed model which seeks to contribute to our understanding of the relationship between emotional/motivational processes, cognitive and metacognitive activities, learning behaviour and learning outcomes. Most of the previous studies on error management and learning from errors focused on workplace learning (Van Dyck, Frese, Baer, & Sonnentag, 2005; Zhao & Olivera, 2006). The proposed model aims to expand this research on the organisational level to learning from errors in general, including academic learning settings. In this regard, our aim is to provide a framework that allows the integration of the different factors targeted in previous research. Relevant theoretical perspectives will be reviewed in the next section, followed by a description of the proposed model. Finally, empirical evidences supporting our assumptions and open research questions will be addressed.

## 2 Theoretical perspectives on learning from errors

Errors are usually defined as an unintended discrepancy between the current and the desired state, or as a deviation from a given standard (Frese & Zapf, 1994). The detection (or external hint by error feedback) of such a discrepancy between the learner's goal and his or her on-task performance is a necessary condition for learning from errors. Thus, in line with the self-regulation literature (Carver & Scheier, 1990; Winne & Hadwin, 1998), we assume that the perception of such a discrepancy – triggered by the detection of an error or error feedback, of whatever kind – is the starting point for processes preceding learning from errors. Contemporary models of self-regulated learning describe a cyclical and recursive process including cognitive, metacognitive and emotional/motivational functioning (Boekaerts, 1999; Pintrich, 2000; Schmitz, 2001; Zimmerman, 2008). In contrast to models proposing several components, these process models outline self-regulated learning as a sequence of events during

the learning process. Therefore, these models appear to constitute a proper basis for describing motivational changes and self-regulatory processes following errors.

The perception of errors and error feedback, respectively, is often accompanied by negative affect. However, learners differ in the way they self-regulate their learning after making an error. The *dual processing self-regulation model* (Boekaerts, 2006; Boekaerts & Niemivirta, 2000) provides an explanation for such differences on the basis of the anticipated threat to self-worth and loss of resources – a likely condition in error situations. The model distinguishes between two main goal priorities which are pursued by self-regulative activities: (1) the "mastery/growth pathway" and (2) the "well-being pathway": Learners who want to reach a goal (e.g. identify their misconceptions after making an error) initiate activities in the mastery/growth pathway because they value that goal and feel competent enough to commit energy to its pursuit. On the contrary, learners who are primarily concerned with the negative consequences of errors initiate activities in the well-being pathway. However, it is assumed that learners can switch to the mastery/growth pathway by using adaptive emotional and motivational regulation strategies (Boekaerts, 2006). Hence, the dual processing self-regulation model emphasizes the importance of affective experiences and the learner's competence to regulate his or her motivation and emotions following errors – fundamental processes that precede actual learning from errors.

In line with Zhao (2011) we define learning from errors as an effortful activity. Our understanding of learning from errors includes a detailed analysis of the error causes in order to identify potential misconceptions, a self-evaluation of the underlying knowledge and its modification, as well as the correction of the error in question, and/or the pointed practice of the type of tasks in which the error occurred. As already noted, we regard the perception of a discrepancy and the learners' striving to reduce this discrepancy as the initiating-point for learning from errors. Similarly, Carver and Scheier (1998) highlighted the role of *feedback control processes* during self-regulation. The core construct in their model is the discrepancy reducing feedback loop or a discrepancy enlarging loop in the case of an avoidance situation. The basic idea is that a given piece of information or the perception of a current situation (input function) is compared to a reference value (goal) or standard. If a discrepancy is detected, adjustments are made in an output function in terms of behavioural changes. For example, a learner may seek further information in the learning material after the perception of an error. Parallel to this behaviour-guiding loop, the authors describe another feedback loop which operates automatically and simultaneously: The affect-creating loop monitors the rate of discrepancy reduction over time. The reference value is "an acceptable or desired or intended rate of behaviour discrepancy reduction" (Carver & Scheier, 2013, p. 178). The output function of this loop adjusts the rate of progress. In our example, the learner may get frustrated or angry after a period of unsuccessful information seeking. The authors further assume that negative affect (as a result of non-congruence between the reference value and the rate of progress) may lead to the enhancement of effort, whereas positive affect may lead to coasting and reduced effort. These assumptions are corroborated by current

research findings (Pekrun, Goetz, Titz, & Perry, 2002; Tulis & Fulmer, 2013) regarding the effects of negative activating state-emotions (e. g. anxiety, anger) and positive deactivating state-emotions (e. g. relief, contentment) on motivation and learning behaviour. Hence – back to our example – feelings of task-related anger may motivate our self-efficacious learner to invest more effort into finding additional information in the learning material in order to identify the underlying misconception (Bandura & Cervone, 1983; Graesser & D'Mello, 2012). On the other hand, it has been argued that activating positive emotions (e. g. task-related enjoyment or interest) may broaden an individual's momentary thought-action repertoire (Fredrickson, 2001) and therefore increase engagement, persistence, and preference for challenge (Linnenbrink & Pintrich, 2004; Pekrun et al., 2002). In short, the theoretical model by Carver and Scheier (1998) provides an appropriate framework for behavioural reactions as well as the origins and functions of emotions that are experienced after errors and error-related changes in one's learning behaviour.

Finally, another model of self-regulated learning can be applied to processes following errors. Similar to the feedback loops described above, the model suggested by Winne and Hadwin (1998) outlines the continuing evaluation of potential discrepancies between products and standards of the learning process. In particular, specific *cognitive processes* and *metacognitive monitoring processes* are highlighted in the model across four phases (for an overview see also Perry & Winne, 2006):

1) It is assumed that learners first develop a definition or model of the task by interpreting task conditions and cognitive conditions (e. g. prior knowledge, or former errors made in similar tasks and strategies that proved effective).
2) In the second phase, learners create goals relative to their model of the task (e. g. to identify their misconceptions and increase task specific knowledge) and select study tactics and learning strategies accordingly.
3) In phase 3, learners engage in learning by applying their chosen tactics and strategies.
4) Finally, learners evaluate the products and – if necessary – adjust their model of the task and adapt goals and strategies accordingly.

Thus, in addition to the adopted models described above, Winne and Hadwin (1998) primarily focus on cognitive and metacognitive activities. Therefore, their model perfectly augments our theoretical framework for learning from errors, which includes motivational, emotional, cognitive, and metacognitive processes and learning activities.

Theoretical considerations which are concerned with learning from errors in a narrower sense focus on the beneficial role of *reflection processes* and *self-explanations* triggered by impasses or erroneous tasks (De Leeuw & Chi, 2003; VanLehn, 1988). VanLehn et al. (2003) suggested that impasses pave the way for learning from the subsequent explanation and therefore are even necessary for learning processes. Supporting this view, Siegler (2002) found students who explained both correct and incorrect solutions during a brief tutoring session were more likely to learn and use correct

procedures that were applicable to a range of problem types than students who only explained correct solutions. By focusing students' attention on errors and deficient concepts, students may be more likely to think deeply about correct concepts and create accurate mental representations that label incorrect concepts as wrong (Oser & Spychiger, 2005; Van den Broek & Kendeou, 2008). For example, the basic idea of the concept of "negative knowledge" (Minsky, 1997; Oser, Hascher, & Spychiger, 1999) is that learners recognise their own deficits when they make errors and initiate reflection processes which result in knowledge about false facts and inappropriate action strategies (for a detailed elaboration of the concept see Gartmeier, Bauer, Gruber, & Heid, 2008). Comparably, Kolodner (1983, 1997) emphasised that errors play a central role in promoting learning because they provide the opportunity for experienced-based reflection. Errors may trigger explanations that might result in reinterpreting former situations or discovering new kinds of interpretations. However, some findings (Große & Renkl, 2007) point to the likelihood that the benefits of studying incorrect examples may only arise for learners with sufficient prior knowledge.

Another line of research and its theoretical basis that seems to be noteworthy with respect to learning from errors is research on volition (Kuhl, 1985). In modern conceptions, volition is being defined as conscious action control which may become automatised (Boekaerts & Corno, 2005; Corno, 2001). Volitional processes are considered part of a broader self-regulatory system and volition theory addresses the *interplay* between cognition, metacognition, motivation and emotion in the face of failure (which can also be applied to error situations). Failure – in contrast to errors – can be defined as a more global miss of a goal with a greater focus on the subsequent negative consequences (Zhao & Olivera, 2006). In order to experience failure, no antecedent errors are essential, because failure can also result as a consequence of external factors. On the contrary, not every error is necessarily interpreted as failure. Whether an error is evaluated as failure or not may depend on situational aspects (e.g. social norms) and/or individual factors, such as the aspiration level of the person. Despite the differences of the concepts "error" and "failure" it is obvious that they are tightly interconnected and therefore mutually dependent: Errors during the course of action prospectively increase the risk of interpreting the result as failure. Otherwise the experience of failure retrospectively promotes attention and the perception of errors in the process of action (Zhao & Olivera, 2006). As defined by volition theory (Kuhl, 2000) it can be assumed that besides "cognitive control" – in terms of metacognitive activity (i.e. to focus attention on the task) – "emotion and motivation control" (aiming at reducing negative emotions and negative intrusive thoughts) mediates the effectiveness of learning from errors. In this sense, some individuals fail in effective emotion-/motivation control and ruminate on past, present, or future states, rather than on options available for action (e.g. analysing the error at hand).

Regarding other individual differences, learning from errors may also be influenced by the learners' attitudes and stable motivational beliefs. Little research has focused on *attitudes towards errors*. Rybowiak, Garst, Frese, and Batinic (1999) developed a questionnaire and proposed several components of an error specific attitude. For example,

"learning from errors" refers to the view of the beneficial role of errors for individual improvement (Rybowiak et al., 1999). "Error competence" refers to the learners' capability to deal with errors immediately when they occur, and "error risk taking" implies a general flexibility and openness towards errors. Both concepts have been found to be positively associated with mastery goal orientation (Arenas, Tabernero, & Briones, 2006; Schell & Conte, 2008). In contrast to performance goal orientation which refers to a focus on the demonstration of one's competence compared to others (or avoiding the demonstration of lack of competence in the case of performance-avoidance goal orientation), mastery goal orientation refers to a focus on skill development and individual improvement. It has been shown that mastery goal oriented students do not necessarily interpret failure as negative (Tulis & Ainley, 2011). These findings are in line with the concept of mastery orientation in which errors are regarded as learning opportunities instead of a threat to self-worth (see Dweck & Leggett, 1988). Attitudes and stabilised motivational orientations such as mastery goal orientation may influence individual reactions to errors and hence learning from them. For example, in the studies conducted by Keith (e.g. Keith & Frese, 2005), the positive function of errors was implemented in an error-management-training by pointing it out to participants while practicing a task. However, error-management-trainings had better effects on performance if they were combined with instructions providing metacognitive techniques supporting cognitive and emotional self-regulation.

In addition to the view that errors are learning opportunities, Dresel and colleagues (Dresel et al., 2013; Dresel & Ziegler, 2002; Tulis et al., 2011) emphasised two individual reaction patterns following errors: The *action adaptivity of error reactions* is defined as the degree to which the learner initiates cognitive processes and behaviours aimed to specifically overcome a possible misconception underlying the present error. For example, it encompasses the detection of the error, an analysis of the error causes, and the identification of misconceptions. The *affective-motivational adaptivity of error reactions* is defined as the degree to which the learner maintains learning motivation and regulates negative affect potentially associated with errors. The latter is assumed to be a prerequisite of action adaptivity of error reactions (Boekaerts, 1999).

In summary, different theoretical and empirical approaches can be applied to error situations. Each of them provides particular aspects that need to be considered in a holistic model regarding individual reactions to and learning from errors. However, most of them describe self-regulation processes in general, but a sufficiently elaborated model with respect to errors as initiating-point for self-regulation is lacking. Other assumptions primarily focus on personal characteristics that may facilitate or impede effective learning from errors, such as attitudes, orientations or personal preconditions. Even the (limited) research that explicitly refers to learning from errors (Bauer, Gartmeier, & Harteis, 2012; Oser & Spychiger, 2005; Van Dyck, van Hooft, de Gilder, & Liesveld, 2010; Zhao, 2011) has rather provided economised working models within the scope of empirical studies than a theoretical framework that allows an application to academic learning contexts. Many of the theoretical assumptions are specifically adapted to vocational learning, and they exclusively address contextual features. For

example, Van Dyck et al. (2005) – exemplary for several studies conducted in the field of organisational error management – focused on organisational error climate. On the other hand, in the context of academic learning Oser and colleagues introduced the concept of "negative knowledge" (Oser et al., 1999; Oser & Spychiger, 2005) whereby learning from errors includes forming (metacognitive) knowledge that helps to prevent repeating errors in similar situations. However – from our point of view – the authors do not pay enough attention to self-regulation processes following errors. Hence, there is a need for a theoretical framework that systematically integrates personal traits, contextual factors and situational regulation processes. We attempt to overcome these existing shortcomings of current approaches and to expand previous concepts regarding learning from errors by providing a framework which combines theories from self-regulation literature, research on volition, emotion and motivation.

## 3 Individual reactions to errors: A process model

Prior to describing our proposed model (see Figure 1) in detail, we would like to refer to its basic points. We assume that a perceived mismatch between the learner's goals and the outcome of their learning activity induces changes in emotional and motivational states. These, in turn, are assumed to trigger regulation processes. We accept the importance of motivational and emotional self-regulation as an essential part of self-regulated learning from errors (Boekaerts & Cascallar, 2006; Butler & Winne, 1995; Pintrich & Schunk, 2002). More specifically, adaptive emotional and motivational self-regulation is acknowledged to be necessary in response to these changes in order to maintain motivation and effort to focus attention and analyse the error at hand. Besides the facilitation of adaptive learning behaviour following errors (e.g. persistence despite obstacles, information seeking behaviour) effective regulation processes further provide the basis for the use of appropriate cognitive and metacognitive strategies to reflect on the underlying misconceptions. As for learning in general (Kanfer & Ackerman, 1989) we assume that besides cognitive resources and metacognitive activities, learning from errors requires motivational forces (inextricably bound to emotional experiences). In particular, our model highlights the functional aspects of emotions accompanying learning from errors twofold:

(1) Emotions act as a signal (Egloff, 2009; Reisenzein, 2006) for the mismatch outlined above and they serve as a monitoring instrument for goal pursuit (Carver & Scheier, 1990)
(2) Emotions guide subsequent learning behaviour, not only in terms of approach or avoidance but also more specifically: Activating emotions – both positive and negative – have been found to facilitate the use of in-depth learning strategies, metacognitive self-regulation and persistent learning behaviour (D'Mello, Lehman, & Person, 2010; Pekrun, Goetz, Daniels, Stupnisky, & Perry, 2010; Pekrun & Linnenbrink-Garcia, 2012; Tulis & Fulmer, 2013).

Comparably, current research emphasises the potential of epistemic emotions (e. g. surprise, confusion) which are experienced when learners are cognitively challenged or face an incongruity (D'Mello & Graesser, 2012; Pekrun & Linnenbrink-Garcia, 2012). Epistemic emotions are assumed to motivate knowledge-generating learning behaviour (e. g. inquiry) and critical reflection. Similarly, "knowledge emotions" are experienced when learners are confronted with information that contradicts existing beliefs or expectations (Silvia, 2010).

In the following, the hypothesised processes and conditions and their theoretical linkages with respect to learning from errors will be described in detail.

Every learning situation is determined through characteristics of the situation and the task, and personal factors which interact continuously with one another throughout the entire learning process. Personal factors include individual preconditions for learning, e. g. prior knowledge or topic-interest (Ainley, Hidi, & Berndorff, 2002) and stable motivational beliefs such as self-concept of ability (for an overview see Dickhäuser, 2006) or the learner's goal orientation (for an overview see Pintrich, 2000). Furthermore, these personal factors encompass the competence of self-regulation, in particular the ability to regulate one's emotions and motivation in error situations. Situational factors include characteristics of the task and the learning context, i. e. the learning environment that may facilitate or impede learning from errors. For example, a positive error climate may foster adaptive affective, motivational, cognitive and behavioural reactions to errors, which, in turn, ensure learning from errors (Oser & Spychiger, 2005; Steuer, Rosentritt-Brunn, & Dresel, 2013). A positive error climate can be defined "as the perception, evaluation and use of errors as integral elements of the learning process, shared in the social learning environment of the classroom" (Steuer et al., 2013, p. 198). It can be described as a multifaceted construct, including reactions by the teacher (e. g. teacher support following errors), reactions from classmates (e. g. absence of negative classmate reactions) and social processes of learning from errors in a narrower sense (e. g. analysis of errors).

It should be noted that our model focuses on intra-individual processes following errors – nonetheless they are influenced by the social context and may occur in collaborative learning settings and with the help of others as well. The interaction between personal and situational factors is affected by previous learning experiences and outcomes which are in turn integrated in a specific social and cultural context. Although personal and situational factors are located at the starting point in our model, they also have an impact on later processes. Learners continuously appraise the learning conditions against the background of their individual preconditions and orientations. Characteristics of the learning environment have an impact on individual processes, i. e. on different stages in the proposed model (which is indicated with dashed arrows in Figure 1). For instance, teachers' or classmates' support following errors may diminish a decrease in self- and task-related motivation. Studies investigating the effectiveness of metacognitive support (Azevedo & Cromley, 2004) have demonstrated their influence on learners' individual use of self-regulated learning (SRL) strategies. Similarly, several intervention studies in the field of SRL have shown that students' use of cognitive, meta-cognitive

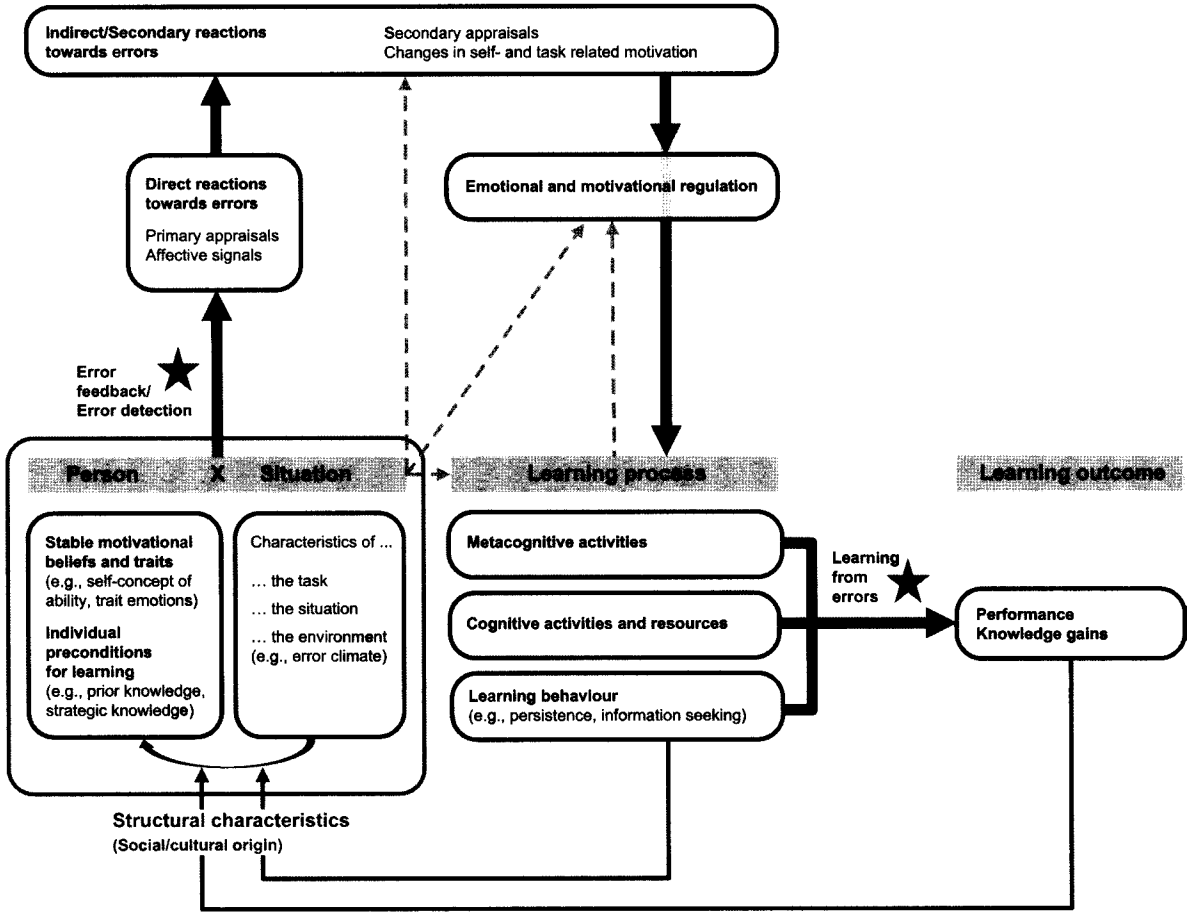


Figure 1: Process model of individual reactions to and learning from errors

and motivational strategies can be promoted directly by external support (Aleven & Koedinger, 2002; Leutner, Barthel, & Schreiber, 2001; Schreiber, 1998).

Finally, research on error management training and error climate (Keith & Frese, 2008; Steuer et al., 2013; Tulis, 2013) has shown that environmental cues, such as training instruction or teachers' error management behaviour, may influence individuals' reactions following errors.

When it comes to an error situation during the learning process, the perception of this specific cue (i. e. bottom-up processing) indicates a mismatch with the learner's current learning intention. Hence, the detection of error(s), through error feedback for example, is assumed to trigger direct reactions which encompass primary appraisals of the situation (Lazarus, 1991): Not only the error *per se* is taken into account, but also its subjective relevance as well as the incongruence with the learner's goals. Goal incongruence is supposed to evoke negative emotions (Weiss & Cropanzano, 1996). However, based on these primary appraisals – and in combination with personal factors in interaction with characteristics of the situation/learning environment – different emotions such as surprise, frustration, anger or boredom may be experienced. At this stage of the model, emotions function as a signal for undesired and unfavourable learning conditions.

Primary reactions are followed by more indirect (i. e. secondary) reactions towards the error at hand, including appraisals of personal resources to minimise, tolerate or eradicate the error (Lazarus, 1991). Furthermore, causal attributions (Weiner, 1986) are made which might evoke other, attribution-dependent emotions than the learner's primary emotional states. Analogous to top-down processing (i. e. knowledge or expectations are used to guide processing), changes in self- and task-related motivation occur at this stage of the model. In line with Boekaerts (2003, 2006), we assume that these changes in motivation and emotional experiences trigger error-related self-regulation processes.

In particular, learners select and use motivational and emotional regulation strategies (Boekaerts, 2006; Gross, 1998; Schwinger, Steinmayr, & Spinath, 2009; Wolters, 1998) to cope with the error situation and to sustain effective learning processes. The regulation strategies that learners may use can be adaptive/adequate or maladaptive/dysfunctional. Some learners may be more concerned with emotion-focused coping (Lazarus, 1993) to avoid a threat to self-worth and restore their well-being (cf. "well-being pathway", Boekaerts, 2006). Others may focus on strategies to re-direct attention and learning activities in order to master the task, which is necessary for learning from errors (cf. "mastery/growth path", Boekaerts, 2006). Particularly, the regulation of deactivating emotions – if necessary – can be assumed as an important precondition of subsequent cognitive and metacognitive activities and learning behaviour specifically adapted to the error (i. e. analysing the error in order to identify misconceptions, select appropriate strategies and invest effort). Dependent on the learners' motivational and emotional states, important at this stage of the model are which strategies learners engage to regulate their emotions and motivation. For instance, overthinking the value of the task, the use of social resources, efficacy self-talk, or cognitive reappraisals may help to reassure the learner to proceed with the task and

maintain learning motivation (Wolters, 2003). In any case, only adequate regulation strategies influence subsequent learning behaviour in an adaptive way. Maladaptive strategies in learning contexts, such as rumination (Knollmann, 2006) may impede a detailed reflection on errors and hence learning from them.

According to our process model, adaptive motivational and emotional self-regulation facilitates further learning processes, including the use of appropriate (meta-) cognitive strategies and learning activities. Learning from errors takes place when learners reflect on their former learning activities and misconceptions and adapt their learning behaviour, cognitive strategies and metacognitive activities to the new situation ("learning process" in Figure 1).

Finally, this should result in the modification of the underlying knowledge, improved skills and performance gains at the end. Learning outcomes are expected to have an effect on the learners' personal preconditions, orientations and beliefs, on the environment, and hence on the interpretation of the situation and a given task.

## 4 Empirical evidence and open research questions

To validate this theoretical framework and to strengthen its empirical base, we exemplarily outline research findings that focused on three different parts/stages of our proposed model in the following. In particular, in previous research we were concerned with motivational and emotional regulation strategies, and the two types of adaptive individual error reactions on the one hand, and contextual factors – specifically, error climate – on the other. Furthermore, we investigated the hypothesised changes in motivation and emotion at the stage pertaining to indirect/secondary reactions towards errors (Dresel et al., 2013; Tulis & Dresel, 2012).

Current research has identified and explored a set of strategies that students may use to self-regulate their motivation (Wolters, 1999). Only a few studies have investigated the predictive value of different motivational and emotional regulation strategies for further learning activities (Schwinger, Steinmayr, & Spinath, 2012). It is still an open question which strategies *specifically adjusted to error situations* might be adaptive or maladaptive. For example, problem-focused coping strategies (cf. "situation modification", Gross, 1998), such as distraction, may facilitate creative problem solving but may impair learning from errors. On the other hand, it can be assumed that failed emotion-focused coping, resulting in rumination (Knollmann, 2006) or maladaptive emotion regulation, such as suppression (Gross, 1998; Gross & Thompson, 2007) have detrimental effects on learning from errors (Zhao, 2011). Finally, different appraisal-focused regulation strategies (for this tripartite classification see Weiten & Lloyd, 2008; also Pekrun, 2011) might have differential effects on error specific learning behaviour. For example, performance goal-oriented self-talk (Wolters, 2003) may be adaptive or maladaptive. In a study by Tulis and Dresel (2012), we analysed $N = 360$ undergraduate students' ($M_{age}$ = 21.9 years, 78 % female) self-reported use of various emotional and motivational regulation strategies following errors in academic settings. Mastery self-talk (i. e. thinking of the potential of errors for personal improvement) and reappraisal

(i. e. having a positive view on making errors as a natural part of learning) were found as the strongest predictors to facilitate the action adaptivity of error reactions, followed by the strategy of proximal goal setting. Distraction and rumination turned out to be the most maladaptive regulation strategies. However, retrospective interviews with $N = 55$ undergraduates ($M_{age} = 20.7$ years, 75 % female) revealed different results compared to process-related, on-task measures: Appraisal-oriented strategies, such as reappraisal or mastery self-talk, were reported more frequently when measured on-task after the error feedback, whereas strategies that aim at the modification of the situation (e. g. distraction, making a break, proximal goal setting) were most prominent when assessed via stimulated recall interviews after the learning session (Tulis & Dresel, 2012). The actual use of regulation strategies is particularly linked with the situation and the task at hand. Learners continuously adjust or change their strategies. Retrospective interview measurements rely upon individuals' abilities to accurately recall variability in motivational and emotional states and the selected self-regulation strategies. Similar to questionnaires, it can be assumed that learners rather report habitualised regulation strategies, i. e. which strategies they tend to use to regulate their motivation and emotions during learning. Retrospective measures might not offer insights into the actual and more transient task-specific regulation processes, especially strategies involving cognitive change. Therefore, such methodological issues should be considered and further investigated in future research.

Using confirmatory factor analyses, Dresel et al. (2013) provided evidence that the two types of individual error reactions are clearly distinguishable from one another. In two studies with $N = 315$ sixth and seventh grade students ($M_{age} = 13.0$, 41.9 % female) and $N = 640$ ninth grade students ($M_{age} = 15.4$, 60.3 % female), model estimation and model comparison revealed advantages for the two-factor model over alternative models (Study 1: $\chi^2 = 184.0$, $df = 61$, RMSEA = .08, CFI = .93, SRMR = .04; Study 2: $\chi^2 = 277.4$, $df = 61$, RMSEA = .07, CFI = .90, SRMR = .08). Furthermore, *action adaptivity of error reactions* and *affective-motivational adaptivity of error reactions* demonstrated different relationships with the learners' individual preconditions, namely stable motivational beliefs (e. g. achievement goal orientation and self-concept of ability). Finally, the action adaptivity of reactions on errors predicted learning behaviour (effort investment, use of self-regulation strategies) above and beyond motivational tendencies and beliefs. This was evident on the level of habitual behaviour patterns and on the level of specific effort investment in the context of specific errors.

Regarding contextual factors which are considered to influence individual learning from errors, Steuer et al. (2013) suggested an eight factor model of error climate and an additional superordinate uniform factor in contrast to a one-factor conceptualisation of the error climate (e. g. DESI-Konsortium, 2008). Based on a questionnaire-study with $N = 1{,}116$ students from 56 sixth and seventh grade classrooms ($M_{age} = 13.1$, 46.4 % female), they provided evidence that a conceptualisation with the following eight distinguishable subdimensions is adequate and advantageous compared to alternative models ($\chi^2 = 1{,}205.5$. $df = 406$, $p < .001$, CFI = .97, TLI = .97, RMSEA = .04):

error tolerance by the teacher (e. g. "In Math our teacher doesn't like if something is done incorrectly"), irrelevance of errors for assessment (e. g. "If someone in our Math class says something wrong, it has an immediate effect on his grade"), teacher support following errors (e. g. "If someone in our Math class can't solve an exercise correctly, the teacher will help him"), absence of negative teacher reactions (e. g. "If someone in our Math class does something incorrectly, he might be mocked by the teacher"), absence of negative classmate reactions (e. g. "If someone in our Math class makes mistakes, his classmates will sometimes make fun of him"), taking the error risk (e. g. "In our Math class a lot of students don't dare to say anything because they are afraid it is wrong"), analysis of errors (e. g. "In our Math class we discuss it in detail when something is done incorrectly") and functionality of errors for learning (e. g. "In our Math class wrong answers are often a good opportunity to really understand the material") (Steuer et al., 2013). Furthermore it could be demonstrated that the error climate predicted individual dealing with errors, namely the affective-motivational adaptivity and the action adaptivity of error reactions. These effects were stable even after including additional (and even more established) characteristics of the learning environment such as the classroom goal structure (Steuer et al., 2013).

Within the same study it was investigated whether the adaptivity of individual error reactions mediated the effects of the perceived error climate on students' effort. The effort scale (Ziegler, Dresel, Schober, & Stoeger, 2005) comprised of seven items assessing behavioural (e. g. "I give a lot of effort prior to Math tests") as well as cognitive (e. g. "I make particular efforts when homework problems in Math are difficult") aspects of effort. Both, the effects of individually perceived error climate ($z > 3.34$, $p < .001$) and shared perceptions of the classroom error climate ($z > 2.34$, $p < .001$) on students' effort were indeed mediated – at least partially – through students' reactions to errors. This suggests that contextual factors, like error climate, have proximate consequences on adaptive reactions to errors, which, in turn, have positive effects on subsequent learning (Steuer et al., 2013).

In general, our research highlights the interaction between individual processes and contextual conditions with respect to learning from errors. Our proposed framework contributes to existing attempts for a theoretical conception of learning from errors by compiling current studies on this topic and integrating models of self-regulated learning and other theories, such as appraisal-theory. We suggest a differentiated and process-related view on individual reactions to errors and their impact on effective learning. Finally, we hope that our proposed model can be used to guide and stimulate future research.

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