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A constructive error climate as an element of effective learning environments

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Abstract

Although making errors while learning is common, it is also frequently perceived by students as something negative, shameful and experienced as a potential threat to self-worth. These perceptions often prevent students from regarding errors as learning opportunities. The result is that the potential to learn from them – which is inherent to errors – is not being realized. However, a favorable error climate can support learning from errors and hence foster learning progress. Based on earlier work our intent was to analyze the factor structure of classroom's error climate (Steuer, Rosentritt-Brunn, & Dresel, 2013). A second aim was to explore different error climate patterns. Finally, we were interested in the interrelations between error climate and student performance in mathematics. These aspects were investigated in a study with $N = 1{,}525$ students from 90 classrooms in German secondary schools in the subject of mathematics. Results were consistent with the presumed factor structure of error climate. Moreover, the results showed a set of three clusters of classrooms with distinct error climates. These clusters additionally support the assumption that differentiating separate error climate subdimensions is important. Furthermore the analyses revealed interrelations between error climate and achievement in mathematics. Here as well, a set of specific subdimensions seems to be related to learning from errors at school.

Keywords: error climate, dealing with errors, classroom environment, achievement

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Environmental characteristics of educational settings have proven to be relevant determinants of student learning (cf. Dorman, Fisher & Waldrip, 2006). Many different factors in a classroom environment have been addressed as important factors concerning learning outcomes. Some examples are teacher support, equity, classroom climate and classroom goal structure (e.g., Fraser, 1989; Klem & Connell, 2004; Meece, Anderman, & Anderman, 2006). This paper focuses on a concept that, although seldom in focus in the past, seems to be fruitful for explaining student learning: error climate (Oser & Spychiger, 2005; Steuer, Rosentritt-Brunn, & Dresel, 2013).

Errors occur in almost all spheres of life, in some they are more salient than in others, e.g. at school. In the scholastic context the absence of errors frequently indicates that something was learned or known. As more errors emerge, the likelihood for bad grades increases in many classroom environments (e.g. Weingart, 2004; Yerushalmi & Polingher, 2006). Thus, errors become negative cues that are associated with negative emotions (like fear, anger or shame) and dysfunctional cognitions. The result is that the potential to learn from them – which is inherent to errors – is not being realized (cf. Oser & Spychiger, 2005). In seeking to increase negative knowledge, a favorable handling of errors in the classroom would be advantageous. Problems in learning are often ascribed to factors within the individual student (cf. Reusser, 2000). However, one cannot disregard the important role a learning environment plays. From research in the field of organizational psychology we know that the environment – depending on the prevalent characteristics – can either foster or hinder learning from errors (e.g. Cannon & Edmondson, 2005; Edmondson, 1996). In the past few years awareness that errors are an integral part of the learning process has increased (Althof, 1999). Still, insights are lacking concerning the processes, mechanisms and necessary antecedents of learning from errors in the classroom.

Theories often cite error climate as important factor, but in empirical studies this construct is often neglected or inadequately differentiated from the individual handling of errors – the latter moreover indicates grave deficits regarding theoretical conceptualization. Additionally, further delineations on other context variables, such as classroom goal structure, are also missing.

Steuer et al. (2013) defined a favourable error climate as the perception, evaluation and utilization of errors as integral elements of the learning process within the social context of the classroom. Consequences of an adaptive error climate are the construction of stable knowledge, the amelioration of emotional states and the generation of better student performance (Spychiger, Oser, Hascher, & Mahler, 1997). Unfortunately, empirical evidence for these assumptions is largely absent at present.

We suppose that the error climate is primarily determined by the behavior of the teacher (e.g. teacher support after errors), nevertheless, the behavior of classmates in error situations also affects this construct. On the whole, error climate comprises the quality and quantity of verbal and nonverbal interactions in the classroom context (Spychiger et al., 1997).

Steuer et al. (2013) proposed eight subdimensions that can be theoretically categorized into three groups. Four of the subdimensions focus on teacher attitudes and teacher behavior. The first aspect (1) *error tolerance by the teacher* comprises an error prevention or error avoidance attitude on the part of the teacher towards mistakes by students (e.g., only addressing questions to students from whom the teacher expects a correct answer). The subdimension (2) *irrelevance of errors for assessment* describes the extent to which student mistakes result in negative evaluations of student performance (i.e. grades). (3) *Teacher support following errors* refers to the measure of help (e.g., further explanations) offered by the teacher following student mistakes. The last of the teacher related dimensions is (4) *absence of negative teacher reactions,* which refers to the degree of disapproval in verbal and non-verbal reactions by teachers to student errors (e.g., demonstrations of anger, annoyance, and ridiculing students).

The next two of the eight proposed subdimensions of error climate in the classroom deal with classmate reactions to errors. One of them is the (5) *absence of negative classmate reactions*. Negative reactions by classmates, for instance laughing or taunting, are usually associated with negative emotions on the part of the student who made the mistake. The other dimension is (6) *taking the error risk.* It describes whether students are confident enough to say something during class without being completely sure if it is correct.

The remaining two of the eight presumed subdimensions of error climate in the classroom refer to the social processes of learning from errors in a narrower sense. One of them is the (7) *analysis of errors.* It describes the magnitude of both analyses of errors and communication about errors. The other is (8) *functionality of errors for learning.* This subdimension describes whether errors are used to initiate learning processes in the classroom. However, it can be assumed that most of the facets described must be established before the functionality of errors for learning can be achieved.

Interplay among the subdimensions of error climate

Due to the fact that error climate is a rather new construct, not much is known about it as a classroom characteristic. Theoretically it is assumed that error climate has multiple favorable outcomes regarding students' learning behavior and performance (e.g., Spychiger et al., 1997; Oser & Spychiger, 2005). The relatively few studies which have been conducted in the educational context do confirm these theoretical assumptions (cf. Steuer et al., 2013). It has been shown that error climate correlates positively with other classroom characteristics like classroom goal structure (cf. Steuer et al., 2013) or characteristics of teaching quality such as classroom management, classroom climate and cognitive activation (cf. Steuer, 2014). Despite these (moderate) correlations the error climate comprises distinct components. Above and beyond the lack of evidence regarding positive outcomes, evidence concerning classroom differences is missing as well. Again, there are some hints of differences between classrooms in the perception of the error climate. For instance, in the DESI-Study[3] relatively huge intraclass-correlations were found for error climate in English and German instruction (DESI Konsortium, 2008). Steuer et al. (2013) found moderate to large intra-

[3] Deutsch-Englisch-Schülerleistungen-International [German-English-Achievement of Students-International]

class-correlations as well for mathematics instruction, which can be regarded as evidence for substantial classroom differences with respect to error climate. Currently, nothing is known about potential specifications or profiles concerning error climates in different classrooms. It is conceivable that the different dimensions of error climate may vary distinctively between classrooms although positive covariations between them have been evidenced in earlier work. This means that different configurations of the error climate dimensions are imaginable. For a functional error climate all dimensions should be evaluated as high, but a simple distinction between high and low may not adequately describe a specific classroom's error climate.

Interrelations between error climate and achievement

The error climate can be regarded as a component of instructional quality in the classroom. It is assumed that a positive error climate in the learning environment enhances the quantity and quality of learning processes, leading in turn to stable knowledge and improved achievement (see Spychiger et al., 1999). More specifically, the rather affective and motivational aspects of an error climate (for example an *absence of negative teacher reactions*) may constitute the precondition for learning from errors in the classroom. The more cognitive aspects (e.g., *analysis of errors*) depict concrete activities and may therefore lead in a more direct manner to increased knowledge.

For context variables, like classroom goal structure and classroom climate, some evidence demonstrates that these constructs and achievement correlate with one another (e.g., Church, Elliot, & Gable, 2001, Walberg, 1990, Wolters, 2004). Concerning error climate in particular, these questions have rarely been addressed in prior research. One exception is the DESI-Study which showed positive correlations between test data and self-reported error climate in the subject of English ($r = .24$ and $r = .25$) (see Helmke et al., 2008). Whether these findings are transferable to other non-linguistic subjects remains an open question.

Research questions

Our first aim was to replicate the error climate factor structure that had already been evidenced in a previous study (Steuer et al., 2013). We expected to confirm two models: one with eight factors and one with the eight factors and one superordinate factor. The second research question deals with potentially different error climate patterns. Under an exploratory focus, we sought to identify different typical profiles of the eight postulated error climate subdimensions. Derived from the assumption of a superordinate uniform factor for classroom error climate, we expected that differences in the overall levels of error climate would be predominant between identified patterns – nevertheless we also expected, to a lesser extent, profile differences (i.e. that different patterns would be characterized by specific strengths and weaknesses in the error climate profiles). A third goal was to examine relationships between error climate and student performance. Based on theoretical considerations and findings from comparable fields of research, we presumed to find low to moderate correlations with achievement measures which should vary with the different subdimensions of error climate.

Method

Participants

The research questions were addressed in a study conducted in the subject of mathematics. The sample comprised N = 1,525 students from 90 seventh, eighth and ninth grade classrooms at different German secondary schools. The proportion of female students was 43% and the average age was 14.4 years (SD = 1.08). Almost 40% of the students had a migrant background and 19% of the students reported that the primary language spoken in their homes was not German. Student participation was voluntarily, but parental permission was required.

Measurements

The perceived error climate in mathematics classrooms was assessed via student perceptions of eight error climate subdimensions utilizing an instrument developed by Steuer et al. (2013). The descriptive statistics are depicted in Table 1. The instrument comprises 31 items in total; each subdimension was measured with three to four items: Error tolerance by the teacher (4 items; sample item: "In Math our teacher doesn't like something is done incorrectly"), irrelevance of errors for assessment (4 items; "If someone in our Math class says something wrong, it has an immediate effect on his grade"), teacher support following errors (4 items; "If someone in our Math class can't solve an exercise correctly, the teacher will help him"), absence of negative teacher reactions (4 items; "If someone in our Math class does something incorrectly, he might be mocked by the teacher"), absence of negative classmate reactions (4 items; "If someone in our Math class makes mistakes, his classmates will sometimes make fun of him"), taking the error risk (3 items; "In our Math class a lot of students don't dare to say anything because they are afraid it is wrong"), analysis of errors (4 items; "In our Math class we discuss it in detail when something is done incorrectly"), and functionality of errors for learning (4 items; "In our Math class wrong answers are often a good opportunity to really understand the material"). Six-point Likert-type scales which ranged from 1 (*strongly disagree*) to 6 (*strongly agree*) were used. The internal consistencies for the eight subscales were acceptable to high on the level of individual perceptions (α = .66–.92). Cronbach's alpha was also computed on the classroom level and good internal consistencies were found (α = .85–.96). As another indicator for the reliability of the subscales, intraclass-correlations ICC2[4] were calculated for the different subscales and were in the acceptable to good range (ICC2 = .61–.81).

[4] The ICC2 can be interpreted as a measure for the homogeneity of student perceptions in the classroom (cf. Lüdtke, Robitzsch, Trautwein, & Kunter, 2009).

Table 1:
Descriptive results of the error climate subscales

	Items	*M*	*SD*	α Student Level	α Classroom Level	*ICC*1	*ICC*2
Error tolerance by the teacher	4	4.19	0.99	.68	.85	.11	.69
Irrelevance of errors for assessment	4	4.21	0.95	.66	.95	.10	.67
Teacher support for errors	4	5.03	1.00	.88	.91	.18	.80
Absence of negative teacher reactions	4	4.80	1.07	.77	.92	.19	.81
Absence of negative classmate reactions	4	4.94	1.14	.86	.96	.08	.61
Taking the error risk	3	3.15	1.18	.84	.92	.14	.61
Analysis of errors	4	4.53	1.26	.92	.95	.08	.75
Functionality of errors for learning	4	4.23	0.99	.86	.91	.09	.64
Superordinate factor	8[a]	4.40	0.64	.73	.87	.23	.84

Notes. *N* = 1,525 students in 90 classrooms. [a] The means of the 8 subdimensions were treated as items in this context.

In order to assess achievement in mathematics independently from teacher evaluations a test – oriented on the scholastic curriculum of grades seven, eight or nine – was used. The test consisted of a set of core items that were assessed in all three grades. The rest of the items were varied so that each student answered 14 items adjusted to the competence level of their respective grade. Each item was evaluated as either correct or incorrect (i.e., rated as 1 or 0). The mean was 7.1 (*SD* = 2.91) and the internal consistency α = .77.

Results

Preliminary analyses

Descriptive statistics including intraclass-correlations for all constructs can be found in Table 1. Moderate to large differences between classrooms were evident with respect to all facets of error climate.

Factor structure of the error climate

In order to confirm the dimensionality of perceived error climate in classrooms (see Steuer et al., 2013), we conducted confirmatory factor analyses followed by two-level exploratory factor analyses using Mplus 6 (Muthén & Muthén, 2010). In order to duplicate the methodical approach used in the first publication (Steuer et al., 2013), we treated all items as ordered categorical variables utilizing a Means and Variance Adjusted Weighted Least Squares Estimator (WLSMV).

Regarding the confirmatory factor analysis, the fit-indices for all three models – the one-factor model, the eight-factor model and the model with eight factors and the superordinate uniform factor – are displayed in Table 2. The first model did not fit the data. In the second model, with eight factors, all items showed standardized loadings on the respective latent variables exceeding $\lambda = .70$. The only exception was one item from the dimension error *tolerance by the teacher*, which showed a smaller loading ($\lambda = .34$). The third model, with eight factors and one superordinate uniform factor, revealed some fit indices that were slightly below the usual cut-off-values. One possible explanation for this could be the subdimension *taking the error risk* which only had a small loading on the superordinate factor ($\lambda = .07$). This dimension also showed the lowest loading in the prior study (see Steuer et al., 2013). Testing the three models against each other revealed that both hypothesized models fit the data better than the one-factor model. Despite being more restrictive, the model with eight factors and a unique superordinate factor (Model 2) showed only a slightly worse fit than the eight-factor model.

In order to collect further evidence regarding the dimensionality of perceived error climate on the classroom level, we performed two-level exploratory factor analyses with Geomin rotation (Muthén & Asparouhov, 2010). A series of models with eight factors on the within-level (as a result from the confirmatory factor analyses) and varying numbers of between-level factors from 1 to 8 were estimated to determine the number of factors on the classroom level. We additionally estimated a model that was unrestricted on the classroom level to obtain a reference for the fit of the previous models. The model with only one classroom level factor had already demonstrated a good fit to the data (χ^2 = 1,048.2; df = 679; $p < .001$; CFI = .99; RMSEA = .02). Between-level factor loadings

Table 2:
Fit-Indices and model comparison of the confirmatory factor analyses of the error climate

Models	*df*	χ^2	*RMSEA*	*CFI*	*TLI*
Model 1: 1-factor-model	434	27771.4*	.20	.55	.52
Model 2 : 8-factor-model	406	3667.8*	.07	.95	.94
Model 3 : 8-factor-model with superordinate factor	426	7221.5*	.10	.89	.88
Model comparison	Δdf	$\Delta\chi^2$			
Model 1 vs. Model 2	26	24103.6*			
Model 1 vs. Model 3	8	20549.9*			
Model 2 vs. Model 3	20	3553.7*			

Notes. N = 1,525 students (within-level) from 90 classrooms (between-level). Analyses were performed with Mplus 6 (Muthén & Muthén, 2010). All items were treated as ordered categorical, utilizing the WLSMV estimator. * $p < .05$.

Table 3:
Results of the two-level exploratory factor analyses of the error climate

Number of factors on individual level	Number of factors on classroom level	*df*	χ^2	*CFI*	*RMSEA*
8	1	679	1048.2*	.99	.02
8	2	649	1103.3*	.99	.02
8	3	620	1110.0*	.98	.02
8	4	592	1110.8	.98	.02
8	5	565	1126.3*	.98	.03
8	6	539	1127.2*	.98	.03
8	7	514	1114.5*	.98	.03
8	8	490	1113.3*	.98	.03
8	unrestricted	245	805.4*	.98	.04

Notes. N = 1,525 students (within-level) from 90 classrooms (between-level). Analyses were performed with Mplus 6 (Muthén & Muthén, 2010), using Geomin rotation. All items were treated as ordered categorical, utilizing the WLSMV estimator. * $p < .05$.

were in the range of $\lambda = .20 - .96$.[5] More complex models did not increase the model fit substantially and showed further disadvantages such as substantial cross-factor loadings on the between-level or non-substantial loadings on postulated factors. Thus, we concluded that a model with eight within-level factors and one between-level factor represents the data well due to the fact that it was the most efficient and easiest to interpret.

Typical error climate patterns in classrooms

In the next step we addressed the question of whether typical error climate patterns could be identified, i.e. clusters of classrooms with similar profiles for the eight subdimensions of error climate. An exploratory hierarchical cluster analysis (using Ward's method and Euclidean distances) with classroom means of the error climate subdimensions suggested a solution with three clusters (referring to the dendrogram). These clusters are depicted in Figure 1. A subsequent 8 (error climate subdimension) x 3 (cluster membership) analysis of variance with repeated measurement on the first factor revealed a large main effect ($F(2,87) = 118.0$; $p < .001$; $\eta^2 = .731$), reflecting large differences in the overall levels of error climate between the three clusters of classrooms. Nevertheless, a moderate to large interaction effect between the factors of error climate subdimension and cluster membership ($F(14,609) = 9.1$; $p < .001$; $\eta^2 = .173$) was also evident. The latter effect

[5] The item with the relatively low loading of .20 was from the subdimension *taking the error risk* ("In our Math class a lot of students would rather say nothing at all than something that is wrong."). All other loadings were at least >= .36 and neglecting the subdimension *taking the error risk* at least >=.53.

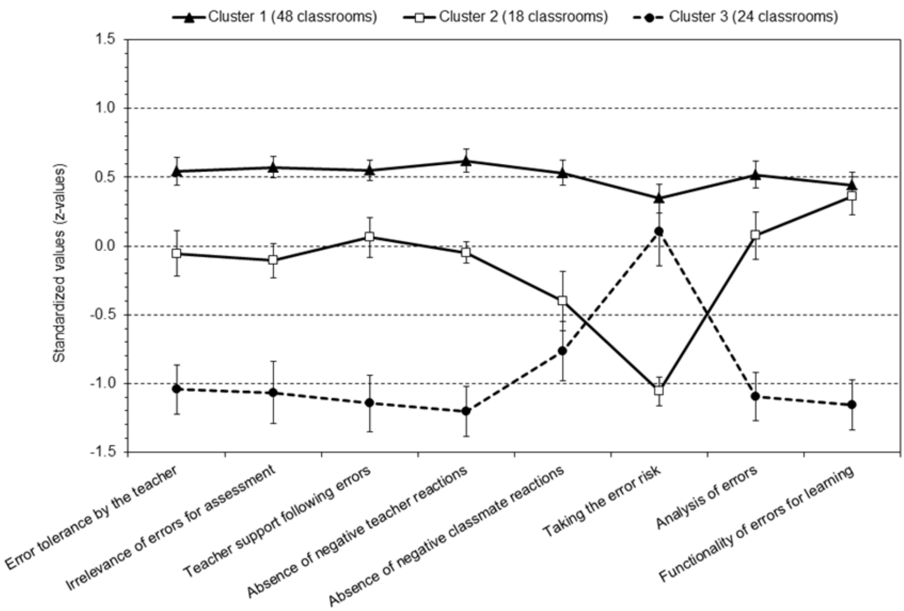

Figure 1:
Means (and Standard errors) of error climate subdimensions for three clusters of classrooms with similar error climates (Presented are values that were standardized on the level of classrooms)

indicates profile differences between clusters beyond overall level differences (rf. Figure 1). More specifically, despite an overall weak error climate in cluster 3, negative classmate reactions were relatively absent and students took the error risk relatively frequently in this cluster. In contrast, these two subdimensions were relatively unfavorably pronounced in cluster 2 – despite an average overall level of error climate and a relatively strong functionality of errors in the learning process. Cluster 3 was characterized by a pattern that reflects a constructive error climate in all subdimensions.

Interrelations between achievement and error climate

We hypothesized that achievement shows associations with the perception of a favorable error climate in a positive manner, as well as for the different dimensions of error climate and with the subordinate factor. Correlations between results on the student performance tests and the various dimensions of the perceived error climate are displayed in Table 4. Positive although rather weak correlations were evident for the superordinate factor indicating that, generally, better evaluations of classroom error climate were associated

Table 4:
Correlations between subscales of error climate and achievement measures

Error climate	Student Level	Classroom Level
Error tolerance by the teacher	.06*	.11
Irrelevance of errors for assessment	.03	.15
Teacher support following errors	.06*	.08
Absence of negative teacher reactions	.01	.00
Absence of negative classmate reactions	–.01	.17
Taking the error risk	.07*	–.05
Analysis of errors	.03	.23*
Functionality of errors for learning	.07*	.18*
Superordinate factor	.07*	.18*

Notes. N = 1,525 students (level 1) in 90 classrooms (level 2). * $p < .05$.

with better achievement. This was evident on the student level and even more so on the classroom level (higher coefficients on classroom levels are common findings).

Additionally, a number of subdimensions were associated positively with student achievement – relatively strong correlations were evident for the aspect of analyzing errors and the functionality of errors in the learning process.

Discussion

Based on earlier work (e.g., Steuer et al., 2013), the central aims of the present work were to examine perceived classroom error climate with regard to factor structure, different profiles and associations with achievement.

The structure of perceived error climate was analyzed by using confirmatory factor analyses (first research question). In accordance to prior results, we could demonstrate that student perceptions of the error climate in the classroom comprise several subdimensions – one can conclude that it is inevitable considering the full breadth of the construct in order to measure and describe the contextual and instructional facets associated with the use of errors in the learning process. This finding underpins the assumed multidimensionality of classroom error climate that had been discussed in prior research (e.g., Spychiger, Mahler, Hascher, & Oser, 1998; Steuer et al., 2013).

Furthermore the subdimensions jointly constitute one superordinate factor which considers students' overall perceptions of classroom error climate. The fit for the "eight-plus-one-model" was slightly worse than that for the eight-factor model, but was still reasonable[6].

[6] For models with large numbers of items and factors, milder interpretations of the cutoff values for acceptable fit indexes are suggested (cf. Marsh, Hau, & Wen, 2004).

Conceptualizing the superordinate uniform factor of the error climate neglects some of the students' impressions, but is generally quite adequate. Nevertheless the subdimensions remain highly significant. Only by considering the breadth of the error climate construct can assessment with sufficient content and construct validity become feasible.

The dimensionality of error climate was not only addressed on the level of students' individual perceptions but also on the classroom level. Often the dimensionality of constructs on a cluster level will differ from dimensionality on an individual level: It is usually simplified (cf. Marsh et al., 2012; Muthén, 1989). The exploratory two-level factor analyses indicated that the unidimensional model of perceived error climate on the classroom level is appropriate. However, the superordinate uniform factor on the level of individual perceptions on the individual level corresponds with a superordinate uniform factor of error climate on the level of shared perceptions within classrooms. As mentioned before, the validity of the uniform classroom level factor is based on subdimensions on the student level.

With respect to the subdimensions of error climate that refer to teacher attitudes and teacher behavior, classmate reactions following errors and the social processes of learning from errors in a narrower sense, we identified three typical patterns in our classroom sample (second research question). In accordance with the confirmation of a superordinate factor of error climate in the classroom, differences in the overall levels of error climate between these identified patterns were predominant. Nevertheless, profile differences between typical patterns of error climates in classrooms were also in evidence, i.e. the three different patterns had specific strengths and weaknesses. This finding additionally underpins the adequacy and usefulness of considering not only an overall measure of classroom error climate but also its various subfacets. The typical patterns found in the present study under an exploratory focus differed particularly with respect to two error climate dimensions that deal with classmate reactions following errors, namely the absence of negative classmate reactions and the degree to which students took the error risk. This can be interpreted through variations in the amount of control a teacher has over the different error climate facets. While the remaining six subdimensions of error climate are more or less under the direct control of teachers, the two subdimensions that deal with classmate reactions are only indirectly controllable by teachers (e.g., by means of an appropriate classroom management or realizing a constructive error climate in other subdimensions).

Regarding the interrelation between error climate and achievement (third research question) small but significant positive associations were evident on both the student and classroom levels. The correlations on the classroom level are particularly significant. We expected rather small effects due to the fact that, on the one hand, the error climate is a rather specific construct that only pertains to an error event or how an error event is handled. Therefore smaller effects were expected than that seen for macroscopic constructs like classroom goal structure or classroom climate. On the other hand, achievement is not determined by a single variable but rather depends on numerous factors such as intelligence, prior knowledge etc.

Another issue is the fact that the direction of the relationship between error climate and student achievement remains unclear. One's (subjectively perceived) achievement has retroactive effects on different motivational variables, but also on the perception of context variables (e.g., Helmke & Weinert, 1997). This means that better achievement leads to a positive evaluation of context variables. Both directions are plausible: positive context variables lead to better achievement, and better achievement leads to a better evaluation of context variables. Most theories of scholastic learning account for these recursive effects (e.g., Helmke, 2009). Previous research on classroom climate has revealed that better student achievement leads to higher ratings in the perception of the classroom climate (e.g., Eder, 1996; Griffin, 2004; Walberg, 1990). Simultaneously a better climate is an important precondition for successful learning. Taking a closer look at the significant correlations of test score and error climate on the classroom level suggests that error climate affects achievement. Analysis of errors and functionality for learning turns out to be important. This indicates that one can learn from errors, especially if the errors are communicated and utilized within the classroom. As a conclusion one can verify that not only emotional climate aspects, but in particular the cognitive aspects of the error climate in the classroom seem to be important for learning from errors.

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