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LEARNING FROM ERRORS:
PSYCHOLOGICAL, RELATIONAL, AND CULTURAL ASPECTS

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Alla mia mamma e al mio papa,
questo risultato parte da voi
e a voi ritorna.
Avete fatto dell'istruzione
un valore fondante della mia vita
e tutti i vostri sacrifici
mi hanno permesso di arrivare qui.

Abstract

Although errors might foster learning, they can also be perceived as something to avoid if they are associated with negative consequences (e.g., receiving a bad grade or being mocked by classmates). Such adverse perceptions may trigger negative emotions and error-avoidance attitudes, limiting the possibility to use errors for learning. These students' reactions may be influenced by relational and cultural aspects of errors that characterise the learning environment. Accordingly, the main aim of this research was to investigate whether relational and cultural characteristics associated with errors affect psychological mechanisms triggered by making mistakes. In the theoretical part, we described the role of errors in learning using an integrated multilevel (i.e., psychological, relational, and cultural levels of analysis) approach. Then, we presented three studies that analysed how cultural and relational error-related variables affect psychological aspects. The studies adopted a specific empirical methodology (i.e., qualitative, experimental, and correlational) and investigated different samples (i.e., teachers, primary school pupils and middle school students). Findings of study one (cultural level) highlighted errors acquire different meanings that are associated with different teachers' error-handling strategies (e.g., supporting or penalising errors). Study two (relational level) demonstrated that teachers' supportive error-handling strategies promote students' perceptions of being in a positive error climate. Findings of study three (relational and psychological level) showed that positive error climate foster students' adaptive reactions towards errors and learning outcomes. Overall, our findings indicated that different variables influence students' learning from errors process and teachers play an important role in conveying specific meanings of errors during learning activities, dealing with students' mistakes supportively, and establishing an error-friendly classroom environment.

Acknowledgement

A professor once told me that doing research is not a lonely process: you think with others, create with others and work with others. At the end of my PhD, I can say that there is no sentence that better represents the way I have learnt and loved doing research during these three years. Therefore, it is time to thank those who helped me make this path possible.

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department and open my mind by discussing PhD students' rights, roles, and responsibilities in society.

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Introduction

Before starting my PhD, I conducted a study where I administered a questionnaire to primary school pupils during mathematics classes. On the day scheduled for the data collection, I walked into a classroom while the mathematics teacher was talking with the pupils about a test they had performed the week before. I introduced myself and asked the teacher to wait outside the classroom until the administration was over, as we had agreed. Before leaving, the teacher said to me in front of the pupils: “Use as much time as you like for the questionnaire: The pupils cannot have playtime today because they made too many errors in the mathematics test.”. I was impressed after hearing that because the teacher had related the errors in the mathematics test to a rather negative meaning (those errors must be penalised) and consequences (loss of playtime) in a single sentence.

Although real, this scenario is exaggerated and unusual. Not all teachers behave this way, and not all students are punished when they make errors. Nevertheless, it made me think about the significance and role of errors in learning. Making errors at school is common because students are often asked to be engaged in tasks above their level of mastery to improve their knowledge and skills. In this respect, it is common to say, “You can learn from your mistakes”, as a way to encourage a meaningful reflection of errors that may lead to learning something new. Several studies have demonstrated that errors could effectively increase learning by activating cognitive and metacognitive processes useful to revise knowledge and start a conceptual change (e.g., Metcalfe, 2017; Kapur, 2009). Therefore, errors should be promoted and included in the learning activities, and students should be scaffolded in taking advantage of them. However, given the teacher’s statement in the example presented above, I wondered whether those pupils would perceive errors in the mathematics test as a source of learning and whether they would be afraid of making errors in the future since they might lose their playtime.

Errors are emotional events *per se* (Zhao et al., 2011), and thus, they may elicit negative emotions (e.g., shame) and threaten students' self-esteem, resulting in decreased motivation and increased errors-avoidance attitude (e.g., Eskreis-Winkler & Fishbach, 2019). How errors are perceived, used and framed in the learning context may impact the affective and motivational processes triggered by errors. Errors have personal and social connotations, and thus, the reactions they foster might vary depending on individual and contextual features (Billett, 2021). For instance, a student might react differently towards the error depending on whether it results in losing playtime or receiving assistance from the teacher to overcome the error. In addition, the same errors could be perceived and judged in opposite ways in a learning environment in which making mistakes is tolerated or, on the contrary, discouraged.

In order to promote learning from errors, it is necessary to take into account different aspects related to making mistakes. More precisely, individual cognitive and emotional mechanisms elicited by making mistakes should be investigated, considering how errors are perceived by the students, as well as handled and used by teachers, and framed in the classroom. Furthermore, broadening the focus, perceptions of errors may also be affected by the cultural values related to mistakes shared in the society at large and conveyed by social institutions (i.e., educational systems).

To date, little is known about students' reactions towards errors (Tulis et al., 2016), and only a few studies have investigated the impact of teachers and the classroom environment on these reactions (e.g., Steuer et al., 2013; Tulis, 2013). Furthermore, to the best of our knowledge, a general overview of relational and cultural variables that may influence the use of error in learning has not yet been provided. Accordingly, the main aim of this dissertation is to analyse whether specific relational and cultural aspects of errors influence psychological (i.e., cognitive, affective, and motivational) mechanisms elicited by making mistakes. More precisely, we investigate the role of errors in the learning process considering

three levels of analysis: psychological, relational, and cultural. As for relational aspects, teacher-students interaction, teacher error handling strategies, and the overall classroom environment will be analysed. As for the cultural aspects, we will examine which cultural meanings related to errors are conveyed by the education systems through teachers' practices, thereby affecting the possibility of learning from errors. The theoretical and the empirical parts of the dissertation are structured according to this multilevel approach (i.e., psychological, relational, and cultural levels of analysis).

In the theoretical part (Chapters 1 – 4), we will present different theories that will be used to frame the empirical section. More precisely, we will explain the importance of analysing the role of errors through the lens of an integrated approach, where constructivist and sociocultural theories are combined to explain the three levels of analysis (Chapter 1). Then, we will summarise the main theories and empirical findings that have already been provided in the literature related to each level of analysis, namely psychological (Chapter 2), relational (Chapter 3) and cultural (Chapter 4). In Chapter 5, the literature gaps in the presented literature will be discussed and related to the empirical studies' research questions.

In the empirical part (Chapter 6 – 8), we will present three studies that differ in the methodologies used (i.e., qualitative, experimental, and correlational) and the samples investigated (i.e., teachers, primary school pupils, middle school students). The three studies mirror the three levels of analysis since they focus on the cultural level (Chapter 6), the relational level (Chapter 7) and both the relational and the psychological levels (Chapter 8). In conclusion, we will discuss the general findings and contributions, pointing out the general limitations and outlining the practical implications of our results (Chapter 9).

Chapter 1

Errors in the learning process

1. Errors and learning: Understanding their relationship through an integrated approach analysis

1.1. Defining errors: A complex phenomenon

Errors are an unavoidable part of our lives. Making mistakes is an ordinary aspect of life, and everyone has experienced errors during various kinds of activities. Since the word *error* (as well as the word *mistake)* may describe different kinds of situations (Hofmann & Frese, 2011), we define which errors we will refer to throughout this dissertation. When the result of an action unintentionally deviates from an expected outcome or the desired goal, an error occurs (e.g., Hofmann & Frese, 2011). Unintentional errors are different from violations, intentional breaches, and conscious transgressions of a rule (Frese & Keith, 2015). Unintentional errors result from a goal-oriented action (Hofmann & Frese, 2011), characterised by an interplay between psychological mechanisms, such as cognitive and metacognitive processes and motivational and emotional regulations.

Since errors are the result of the deviation from an expected outcome, it is possible to argue that—when detected by the actor or an observer—they function as a sign that the action did not achieve the expected goal. They also signal that something needs to be changed, and thus, they can potentially lead to improving learning. For instance, in the school context knowledge- and rule-based mistakes due to an erroneous concept or flawed mental processes may have a role in the learning process because they note that a conceptual change is needed (Tulis et al., 2016).

Furthermore, according to Billett (2012), errors are more than an objective deviation from certain norms or expectations: They also have a social connotation that determines their

social meaning. In other words, not all errors are perceived in the same way by different people and in different situations. Their meaning is built in line with cultural values and social norms shared in the context where they occur. For instance, the same error in a performance test can be perceived as an opportunity to learn or a sign of failure depending on the error tolerance expressed in the classroom and the consequences that follow that error. Therefore, personal, situational, and contextual factors may jointly influence how learning can emerge from an error.

From now on, we will use the words *error* and *mistake* interchangeably to indicate different unintentional errors that occurred in schools, such as incorrect answers, misconceptions, erroneous solutions, and inaccurate reasoning procedures. The following parts will focus on understanding how errors in school and learning are related and how errors can be used as a source of learning.

1.2. Defining learning: Different meanings for different approaches

Learning is defined as a change in behaviour, knowledge, or brain function observable in a person due to acquiring new information, knowledge, and skills through practice, observation, or other experiences (see APA Dictionary of Psychology). When considering how learning takes place and the factors that determine it, explanations may vary based on the theoretical lens through which learning is described. The learning process could be viewed as the transmission of knowledge from a teacher to a learner without any further elaboration. The best result is due to the similarity between what is transmitted and what is repeated. Incorrect responses are punished, whereas correct responses are followed by reinforcement to shape students' behaviours. On the contrary, learning may be conceptualized as the result of the individual elaboration of information and cognitive processes regulation, implying a co-construction of meanings built within the learner-context relationship. The role of students in

giving sense to, using, and manipulating information is central, as is their relationship with the environment and the context at large.

The meaning of errors changes accordingly. The first definition of learning is derived from behaviourist theories (e.g., Skinner, 1953), which focus on observable behaviours determined by responses to environmental stimuli. Associations between responses and stimuli are the basis of the learning process, which is entirely shaped by the environment. Therefore, mistakes are viewed as incorrect responses that should be avoided or detected and punished. The second definition of learning given above refers to constructivist theories (e.g., Gelman, 1994). According to these theories, environmental stimuli are embedded in the mental structures through the learner's active elaboration and interpretation (see Carugati & Selleri, 2005). Errors should be considered part of the learning process in this framework since they constitute an external stimulus that functions as a signal that may lead to modifications in an inaccurate concept or schema.

Broadening the focus, and in line with Billett (2012), understanding the relationship between errors and learning necessitates considering contextual factors that can shape how individuals perceive errors. Sociocultural theories advanced in this regard, emphasizing the role of interactions, as well as social and cultural features, in shaping how learners actively build their knowledge and skills (Mason, 2006). According to these theories, the learning process is characterised by social interactions between different actors (e.g., the teacher-student relationship) and influenced by the cultural and social context. Therefore, analysing the learning process entails investigating the learners' psychological mechanisms in the light of the cultural values and the social norms expressed in the society and conveyed within social interactions.

Mason (2006) argued that an integrated approach based on "bridging" (Mason, 2006, p. 62) internal (i.e., psychological dynamics) and external (social and cultural facets) factors

could address the complexity of the learning process by integrating the different aspects that influence it (see also Billett, 1996). Accordingly, in this dissertation, we will investigate the role of errors in the learning process through the lens of constructivist and sociocultural theories. The former account for psychological mechanisms, whereas the latter for social and cultural features related to learning.

2. Psychological and socio-cultural aspects together: The theoretical background

As stated in the previous section, an integrated approach that bridges psychological and sociocultural aspects may account for the complexity of the learning process in general and learning from errors in particular. Therefore, this section describes two theories that serve as the theoretical background of this dissertation. On the one hand, we present some aspects of the self-regulated learning theories (e.g., Schunk & Green, 2018) that provide an integrated overview of the psychological mechanisms involved in the learning process. On the other hand, we briefly introduce the cultural-historical theory of Lev Vygotsky (1978), in particular, the conceptualisation of social and cultural influences on the learning process. It is important to note that the purpose of presenting these theories is to show the reader which are the two general sources of theoretical inspiration for this dissertation and not to compare them. Even though both theories examined different dimensions related to learning (i.e., psychological, relational, and cultural), they emphasised these aspects differently. Furthermore, because this is not the appropriate place for a detailed explanation of both theories, we will only briefly summarise some characteristics of each theory in the parts that follow without claiming to be exhaustive.

2.1. Focus on psychological aspects: Self-regulated learning processes

Over the last 30 years, literature on self-regulated learning has expanded considerably, providing different theoretical approaches and empirical results related to how and under what conditions learners become self-regulated learners. For this reason, this section aims to define the self-regulated learning process without claims to be exhaustive. The Cyclical Phases Theory of Zimmerman (2000) will be used as an example (for a systematic review of different self-regulated learning theories, see Panadero, 2018) to provide a general overview of self-regulated learning processes. In addition, for the sake of clarity, we briefly reported the description of processes in the main text. The definitions and clarifications of the four main characteristics of self-regulated learning (i.e., cognitive and metacognitive strategies, emotional and motivational mechanisms) can be found in Box 1.

Self-regulated learning refers to "how students personally activate, alter, and sustain their learning practices in specific contexts." (Zimmerman, 1986, p. 307). Self-regulated learning is based on being cognitively, metacognitively, motivationally, and behaviourally active in the learning process. Goal setting and striving sustain self-regulated activities, which are characterized by cyclical processes based on a feedback loop, which could be internal (e.g., self-monitoring) or external (e.g., teachers' feedback). Furthermore, motivation and emotions have a core role in fostering self-regulated activities and helping the student understand environmental cues (see Box 1).

The Cyclical Phases Model presented by Zimmerman (2000) includes three main interconnected phases. In the first, *Forethought*, the student uses cognitive strategies to set the goal and plan activities to reach that goal. These strategies are enacted only if the student is motivated to pursue the goal and, at the same time, if the student feels positive emotions, which are fundamental to using adaptive strategies for learning. Once goals and activities are

set, during the *Performance* phase, the student starts working while constantly monitoring the activities.

Box 1. Cognition, metacognition, motivation, and emotions: Psychological mechanisms of self-regulated learning

According to self-regulated learning theories, the four basic psychological mechanisms involved in learning are cognition, metacognition, motivation, and emotion. Each of them is briefly defined here, along with their role in facilitating learning.

Cognitive processes are divided into two main groups: information-related strategies, which are learned, and basic processes, which are considered innate. The former group comprises strategies addressed to information processing, such as encoding, retrieving, comprehending, predicting information. On the contrary, innate cognitive processes can be encapsulated in the acronym SMART: searching, monitoring, assembling, rehearsing, translating information (see Winne, 2018). Metacognition comprises all the strategies used to think, evaluate, and change cognitive processes. In other words, metacognitive strategies help the learner monitor knowledge and thoughts, set goals to achieve, understand, and activate procedures to reach the goal and evaluate progress (Lajoie, 2008).

In some self-regulated learning theories, specific cognitive and metacognitive processes are considered more central than others. For instance, Winne and Hadwin (1998) considered monitoring (cognitive) and goal setting (metacognitive) the essential activities to sustain learning. The model proposed by the authors highlighted the key role of an ongoing assessment of the potential discrepancies between outcomes and learning standards. In the Cyclical Phases Model (Zimmerman, 2000), constant assessment of performance, internal and external attribution are considered fundamental processes to foster self-regulated learning.

Motivation (defined as *intrinsic motivation*, the internal boost that pushes people to engage in activities; Ryan & Deci, 2000) is a transversal aspect that has a role in different models and different phases of self-regulated learning. Regulating motivation helps support learning in general (Printch, 2004) and adopt metacognitive strategies, such as planning activities and setting goals (e.g., Winne & Hadwin, 1998).

Unlike motivation, emotions have not been considered transversal characteristics of self-regulated learning, but some theoretical models gave them a central role. For instance, in the Dual Processing model of Boekaerts (Boekaerts & Cascallar, 2006), emotional appraisals guide students in pursuing the goal by activating two different pathways. If the students perceive the task as threatening, negative emotions arise, which prompt strategies to protect the ego (i.e., well-being pathways). On the contrary, positive emotions occur if the task is congruent with the students' knowledge and expectations. In this second case, cognitive strategies are directed to gain more knowledge (i.e., growth pathways). Emotional regulations function as a signal to guide students in understanding the task. Efklides (2011) provided evidence that emotions, motivation, and metacognitive processes affect each other reciprocally. According to the author, a negative mood increases the reported feeling of difficulty (resulting from a metacognitive evaluation), and, at the same time, metacognitive processes trigger achievement emotions (Efklides et al., 2018).

This phase requires the student to analyse the external feedback and change strategies and actions. Again, the motivational and emotional aspects are essential: If the student receives negative feedback, dysfunctional emotions may arise (such as hopelessness), which determines a maladaptive self-monitoring process. Finally, a third phase starts, the *Self-reflection* phase, in which the student can evaluate progress and results and make external or internal attributions of success or failure (see Zimmerman, 2000; Panadero, 2018).

The three phases described by Zimmerman (2000) could be applied to the situation in which students make mistakes. For instance, the constant self-monitoring and self-evaluation of performance, specific aspects of the Performance and Self-reflection phases, are fundamental for detecting and processing errors while performing an activity (Tulis et al., 2016). Indeed, the cognitive strategies implemented during the Self-reflection phase are linked to better learning performance after making mistakes (Heemsoth & Heinze, 2016) and help students reflect on mistakes and the rationale behind them (Ramdass & Zimmerman, 2008). Furthermore, since making mistakes is considered an emotional event *per se* (Zhao, 2011), the self-regulated learning theories, which emphasise continuous emotional and motivational regulation, take into consideration all the aspects triggered by the error detection.

Although self-regulated learning theories have focused more on psychological aspects, the learning context and the social dimension of learning have received attention. Zimmerman (1986) pointed out the importance of considering self-regulation strategies in a specific context. In the same paper, the author underlined that "self-regulation is not an idiosyncratic product of a child's own discovery experiences, but rather, it is a culturally transmitted method for optimizing and controlling learning events. Implicit in this account are assumptions about the importance of the relationship between children and their socializing agent […]" (Zimmerman, 1986, p. 311).

Self-regulated learning happens inside a context: External feedback and the larger social context play a substantial role in determining how the student can effectively become a self-regulated student. In line with this and to account for the importance of the external context—seen as relational, social, and cultural aspects of an environment—we will briefly describe the theory of Lev Vygotsky, in which these aspects acquire a central role.

1.2. Focus on social and cultural aspects: The theory of Lev Vygotsky

The theory of Lev Vygotsky expanded the constructivist approach by pointing out the key role of social and cultural aspects in determining the learning process and, more generally, individual development. According to Vygotsky, all the psychological functions are firstly acted by the person (i.e., the child) during social interactions and, secondly, internalised. For instance, the development of language, considered one of the most fundamental high-level psychological functions, is based on two main steps. First, the child engages in social activities in which the language is an external and cultural tool that allows the interaction to take place. Second, language becomes an individual and internal activity that leads the child to regulate his/her own behaviour and program his/her actions. Through the internalization process, all the external values, beliefs, and attitudes, culturally determined and shared within society, make up individual psychological processes that become internal. The language supports the child's cognitive development and, at the same time, is the cultural tool (i.e., symbolic system) that is conveyed from one generation to another (e.g., Mason, 2006; McInerney, 2005).

In Vygotsky's theory, culture becomes an active actor that contributes to shaping child development and, in turn, the learning process. Culture comprises all the socially accepted behaviours, attitudes, and beliefs transmitted from one generation to another through societal products, such as institutions (e.g., the education system) and symbolic systems (e.g., language). Therefore, development and learning should be interpreted considering the

artefacts (e.g., cultural tools, social norms and institutions, beliefs and representations; Carugati & Selleri, 2005; Cole, 1996) culturally defined and transmitted within social interactions.

In line with that, every phenomenon related to learning (in this case, the possibility of learning from errors) must be understood in light of all the cultural meanings which are transmitted within teacher-student relationships. In other words, students are socialized to their culture through the transmission of cultural meanings embedded in the cultural artefacts. In the school context, the teacher-student relationship represents the space in which cultural artefacts are conveyed from one generation to another (Carugati & Selleri, 2005). In other words, students are socialized to their culture by teachers who transmit cultural artefacts while interacting with them during learning activities.

The importance of social relationships in shaping learning is also expressed by the notion of the Zone of Proximal Development. The Zone of Proximal Development (ZPD) is defined as the distance between the actual learner's level of mastery and his/her potential level of accomplishment (see, Selleri & Carugati, 2005). Learning takes place in the ZPD, in which learners should accomplish their highest level of mastery sustained and helped by a more competent person (i.e., the teacher) (Vygotsky, 1978). The notion of the ZPD relies on the idea that learning does not happen without socialization. This idea that social interactions are key factors in determining the learning process is at the heart of other theories developed in the light of the sociocultural approach, such as the sociocognitive conflict theory (Doise & Mugny, 1984).

In this dissertation, we attempted to interpret and analyse psychological mechanisms (i.e., self-regulated learning process activated after making mistakes) considering the social and cultural aspects in which they occur. We, therefore, focused on the role of the social interactions between teachers and students, viewing teachers as agents of socialisation (Butera

et al., 2021), and we considered which cultural meanings embedded in the society related to errors are conveyed within the teacher-student relationship.

2. Errors in the learning process: psychological, relational, and cultural facets

Having presented self-regulated learning and the Vygotskian theories, which function as a broad theoretical background, in this section, we briefly introduce the multilevel structure of this dissertation. Adopting an integrated approach that combines constructivist and sociocultural theories requires considering several aspects of the learning process that reflect multiple levels of analysis. We propose a three-level approach analysis based on the conceptual framework of the four levels of explanation in social psychology (i.e., intra-individual, inter-individual, positional, and cultural; Doise, 1986). Accordingly, we analysed the learning from errors process considering psychological, relational, and cultural aspects. We define these levels using the definitions proposed by Mercer and Littleton (2007).

The psychological level refers to all the processes related to individual learning and cognitive development. These processes are the micro facets of learning phenomena that determine how individuals (i.e., students) can learn. The focus is on internal psychological mechanisms, such as emotions and motivation, which guide the interpretation of situations, as well as cognition and metacognition, which support knowledge acquisition. Psychological mechanisms are intertwined with interpersonal relationships, and thus, should be interpreted in the light of relational aspects related to learning.

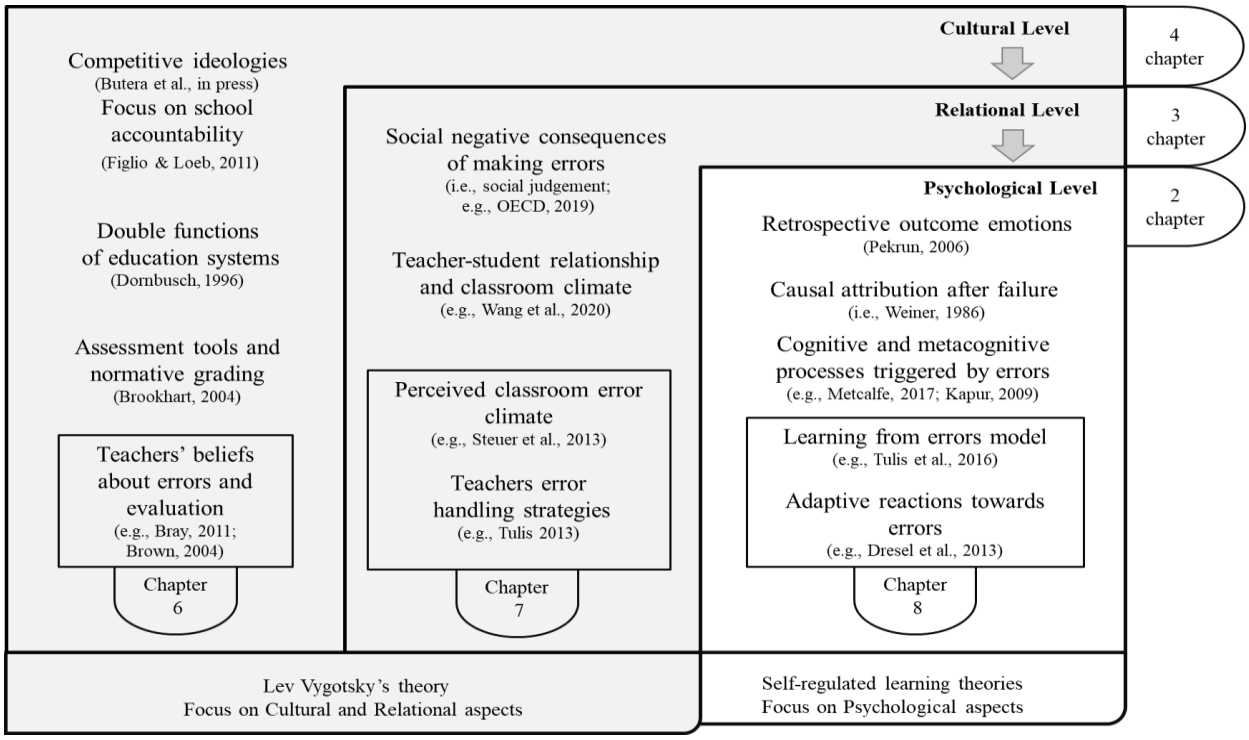
The relational level encompasses all the interactions within a group and between individuals and bridges the psychological and cultural levels (Mercer & Littleton, 2007). Through relations with classmates and teachers, students are socialised to the culture of the community and society. They understand how other people perceive the context and make sense of their experience. This level also refers to all the social activities of the classroom

(e.g., strategies to deal with students' errors, evaluating performance, group discussion) and the social dynamics that determine interactions in the classroom (e.g., social comparison, competition).

The cultural level includes all the meanings, values, and norms culturally determined and shared in the society. Institutions, such as educational systems, contribute to transmitting throughout generations cultural values and social norms. Educational systems shape pedagogies, educational goals, and expected results of learning that mirror culture and society's needs.

Figure 1

Theoretical and Empirical Structure of the Present Dissertation



Note. In the theoretical section several theories are presented, divided into the three levels. The key theories are depicted in the boxes, which are presented in depth in the theoretical chapters (chapters 2 – 3–4) and analysed in the empirical chapters (6 – 7–8). In the bottom part of the figure the two main theoretical background are presented and linked to the respective levels (i.e., The psychological level is related to the self-regulated learning theoretical background, whereas the relational and cultural level to Vygotsky's theory).

The multilevel approach represents the structure of the dissertation for both the theoretical and the empirical parts. More precisely, each chapter of the theoretical section

(Chapters 2-4) focused on one specific level of analysis, presenting relevant theories related to learning from errors. Furthermore, each empirical research chapter (Chapters 6-8) studied in detail one aspect related to learning from errors. In Figure 1, an overview of the following sections and the related chapters is provided.

3. Conclusion

This chapter presented the broad theoretical frameworks that serve as a background for this dissertation. More precisely, we described the self-regulated learning theories as a framework to understand the psychological processes involved in learning from errors and Lev Vygotsky's theory, which documented the importance of social and cultural facets of learning. Furthermore, we briefly introduce the levels of analysis (i.e., psychological, social, and cultural; Mercer & Littleton, 2007) through which we will interpret the role of errors in the learning process.

The following three chapters delve more in-depth into the three levels of analysis, presenting literature related to psychological dynamics, relational aspects and cultural features involved in the learning from errors process. It is worth noting that in explaining relational (i.e., teachers' error handling strategies) and cultural aspects (i.e., evaluation system), we will not use the word *feedback* itself, although we refer to this concept. Hattie and Timperley (2007, page 81) defined feedback "as information provided by an agent (e.g., teacher, peer, book, parent, self, experience) regarding aspects of one's performance or understanding". This broad definition of feedback includes a variety of responses from teachers to students, and several scholars have used the term *feedback* to describe a range of responses (see George & Pansu, 2011). Teachers' error-handling strategies (i.e., how teachers react and respond to students' errors, Chapter 3) described in this dissertation are similar to the type of feedback outlined by Kluger and DeNisi (1981), Butler and Winnie (1995), and Brophy (1981).

Similarly, the evaluation system (Chapter 4) may be considered *feedback*, regardless of the assessment technique employed (judgments, formative descriptions, or grades). What evaluation does is provide feedback to the student on his/her performance achievement or his/her learning path. In this way, grading, as described in Chapter 4, is comparable to Hattie and Timperley's (2007) definition of self-level feedback, namely feedback that expresses an evaluation of the student

Since the literature on feedback is vast and this word can refer to different meanings, we preferred to use more specific concepts of error-handling strategies and grading instead of speaking more generally about feedback. In the following chapters, both self-regulated learning processes, teacher strategies, and grading specifically focus on the role of errors in the learning process.

Chapter 2

Psychological aspects related to errors and the learning from errors model

1. The role of errors in learning at the psychological level

Considering the psychological aspects of errors in the learning process means understanding which internal mechanisms promote the possibility of learning from mistakes as well as which individual reactions are triggered by making errors. Research focused on cognitive and metacognitive processes showed that making mistakes may boost learning. Metcalfe's (2017) literature review on brain activities and cognitive processes involved in learning from mistakes pointed out that errors can enhance memory skills in different domains, promote self-reflection, and drive attentional resources.

In the works on productive failure carried out by Kapur (2009; 2011; 2014), the exploration of mistakes during collaborative computer-based mathematics exercises enhanced students' performance in mathematics. According to the author, mistakes made students aware of their knowledge limits, thereby creating the condition to reflect more thoroughly on their concepts. Furthermore, by comparing their erroneous solutions with the correct ones, either individually or in a group situation, students focused more on the problematic aspects of the new concept. In the same line, errors detection has been found to promote students' performance above and beyond other individual factors, such as learning strategies (i.e., cognitive and metacognitive processes) and achievement motivation (Zamora et al., 2018).

Besides cognitive processes, emotional reactions may occur after errors. Making mistakes is an emotional event *per se* (Zhao, 2011), and thus, emotional appraisals may arise (Lazarus, 1991). According to Eskreis-Winkler and Fishbach (2019), detecting errors can threaten people's self-esteem and self-worth and undermine their motivation to achieve. In

this respect, the causal attribution process plays an essential role in directing emotional and motivational regulations (e.g., Weiner, 1986). Causal thinking comprises three dimensions: the locus (i.e., internal or external causes), the stability (i.e., stable or unstable causes), and the controllability (i.e., individual control of the causes). After erring, the student starts a process to understand the causes of the error. Errors may be perceived as internal, stable, and not controllable (e.g., the error is due to a lack of intelligence, which the student cannot change), or internal, unstable, and controllable (e.g., the error is due to a lack of study and the student can strive more next time). The causal attribution process fosters different emotions related to mistakes, such as shame or anger. Furthermore, attributions are associated with students' motivation to strive and engage in future tasks (Weiner, 1986).

Most of the research on psychological mechanisms related to errors has focused on cognitive and metacognitive processes. In contrast, only a few studies have attempted to explain error-related emotional and motivational regulation. To fill in this gap, Tulis and colleagues (2016) proposed a comprehensive theoretical model based on self-regulated learning theories in which all these mechanisms have been linked together. This model (Tulis et al., 2016), representing a suitable theoretical framework that accounts for the complex interplay of different psychological mechanisms, will be presented in the following sections.

2. The learning from errors model

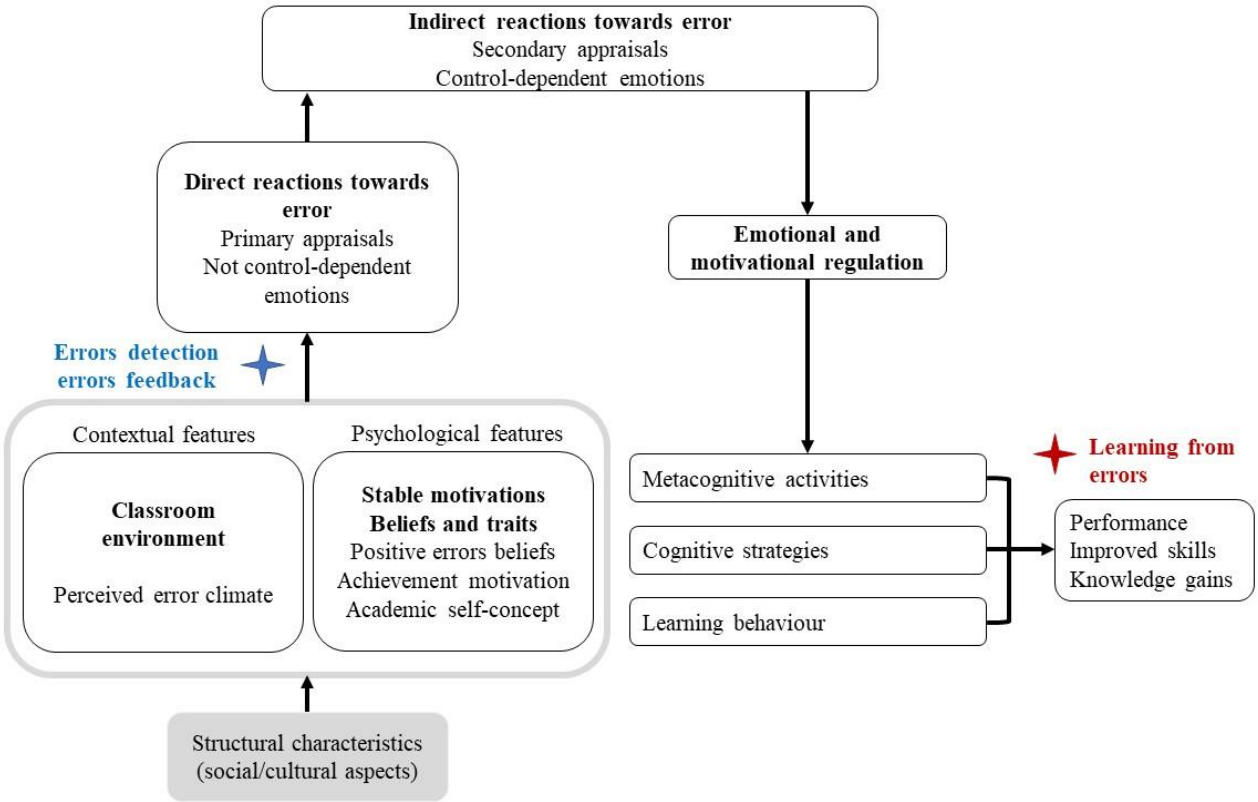
Learning from errors can be considered a "specific learning phenomenon" (Tulis et al., 2016, p. 13), and thus, to explain its complexity, it is necessary to consider different dynamics by including emotional and motivational aspects. The learning from errors model has been elaborated and presented to address this gap and the self-regulated learning theories, which consider the interplay between cognitive and metacognitive dynamics as well as emotional and motivational changes (e.g., Panadero, 2018; Schunk & Green, 2018), account for the

complexity of the learning from errors process (Tulis et al., 2016). Therefore, the model is based on different aspects of self-regulated learning (e.g., Boekaerts, 2006; Winne & Hadwin, 1998), including literature on stress and coping (Lazarus, 1991), attribution theory (Weiner, 1986), and emotions (e.g., Pekrun, 2006).

Figure 2, adapted from Tulis and colleagues (2016, p.19), shows the self-regulation processes activated by error detection (the blue star in Figure 2). In the left part of the figure, individual features are represented; in the right part of the figure, the expected outcomes (i.e., better performance, knowledge gains) are shown. Here, we describe only some individual features listed by the authors in the original model that are related to learning from errors (i.e., academic self-concept, errors beliefs). The environment features (bottom left-hand part of Figure 2) will be described in Chapter 3.

Figure 2

The Learning from Errors Model. Figure Adapted from Tulis and Colleagues (2016, p. 19)



1.1. What happens when a student makes an error: Emotional changes

To clearly explain the intra-individual processes (i.e., self-regulation processes) that error detection activates in the student, we will use a practical example. One of the most common tools that teachers use during the lesson to build a dialogue with students is asking questions (Mercer & Littleton, 2007). Thus, we can picture the following situation: During a math class, the teacher explains the rule to compute the perimeter of a square. The teacher proposes a problem, and, after giving all the necessary data to the students to make the computation, she asks for the solution. Several students raise their hands to reply to the question. The teacher chooses one student who replies. “No, that is not correct!” is the following response of the teacher. The student has just made an error. Starting from this point, something happens inside and outside the student. At this moment, the learning from errors process begins (the blue star in Figure 2).

Immediately after the error detection, a first affective reaction starts. According to Lazarus (1991), when there is a mismatch between the expected performance and the effective result (i.e., an error), the learner needs to evaluate the relevance of this unintended discrepancy. When the student in our example recognises that the response deviated from some expectations, emotional changes (i.e., two subsequent emotional appraisals) help the student to assess the situation. This first appraisal is characterized by emotions, such as surprise or disappointment, that is not fully defined and understood by the learner. As a result of this confusing initial emotional appraisal, a clearer set of emotions emerges. This second indirect appraisal contributes to a better understanding of the situation by helping the student in assessing the causes of the problem as well as the personal capabilities necessary to overcome the issue (Lazarus, 1991).

In the transition between the first emotional appraisal and the second causal attribution, a cognitive process plays a significant role. In attributional theories, emotions

related to failure and success are determined by the attribution of the cause that led to a particular outcome (i.e., failure or success, Weiner, 1985). How the students attribute the locus (internal or external), the controllability (under control or not under control) and the stability (stable vs unstable) of the cause of failure or success determines the subsequent emotional appraisal. Therefore, causal attribution is necessary to guide the student to understand the cause of a failure situation, which in turn, leads to a particular emotional appraisal. For instance, if the cause of a failure is considered stable and internal (e.g., lack of ability), the student may experience hopelessness or shame. For this reason, causal attribution of success and failure is considered the most important antecedent of emotions related to achievement outcomes according to Weiner's theory (1985).

Another interesting theory of emotional appraisal is the control-value theory of achievement emotions developed by Pekrun (2006). Achievement emotions are emotions directly related to achievement activities (e.g., classroom learning activities) and outcomes (e.g., succeeding in a school test). Unlike attributional theories (Weiner, 1985), in Pekrun's idea, control and value are considered the first appraisals of achievement emotions. Control is the students' perceived controllability of particular achievement activities or outcomes. Value is the subjective importance of these activities and outcomes. In other words, achievement emotions are elicited according to the feeling of being in control of (or not in control of) activities and outcomes considered important (or not) for the students (Pekrun & Stephens, 2010).

Based on these two appraisals, it is possible to distinguish prospective outcome emotions (e.g., anticipatory joy or hopelessness before the outcome), retrospective outcome emotions (e.g., sadness or disappointment after a negative outcome), and activity emotions (e.g., frustration and enjoyment experienced during the activity, Pekrun, 2006). Retrospective outcome emotions are further distinguished into *control-independent* and *control-dependent*

emotions. The former refers to emotions that arise even though the learner has not already understood the causes of the outcome. In other words, when an error has occurred, sadness may immediately arise before the learner has made causal attribution. Therefore, the first direct reactions towards errors described by Tulis and colleagues (2016) could be considered as *not control-dependent emotions*, which arise before attributing a cause and understanding of the situation.

The *control-dependent emotions*, on the contrary, are related to the causal attribution of the action (e.g., pride if the causal attribution is internal for success, anger if the causal attribution for failure is external), and they arise in a second moment (secondary emotional appraisal described in the Tulis' model). Therefore, considering Pekrun's (2006) model, causal attributions have a pivotal role in regulating emotions as well and helping students navigate the failure situation.

Besides the differences between Pekrun's (2006) and Weiner's (1985) perspectives on the role of *control* (see, for instance Pekrun & Stephens, 2010), the value dimension of the control-value theory is particularly important here. Indeed, considering the degree to which students judge valuable or important an achievement outcome may change the emotions felt after an outcome (e.g., after a negative outcome, such errors). For instance, if the student is interested in the subject, or if the outcome determines his/her possibility to pass or not the school year, the subjective value attributed to that outcome is very different than in the opposite situation, when the student is not interested at all. The value dimension could change the emotional regulation and the subsequent self-regulation strategies (see next paragraph) adopted after making errors.

Coming back to our scenario, when the teacher gives the error feedback, the student feels negative emotions, such as sadness (i.e., first emotional reaction towards errors), which are followed, for instance, by internal and controllable causal attribution (e.g., "I made a

mistake because I did not understand the formula well"). At this point, the student may feel negative *control-dependent emotions*, such as shame, which may have detrimental effects on motivational processes (Pekrun et al., 2010). However, personal features (left part of Figure 1) may play a key role in determining the subsequent emotional and motivational self-regulation processes. For instance, Tulis and Ainley (2011) showed that positive orientations towards mistakes and mastery orientation support students' positive emotions after failure feedback. The student of our example is mastery-oriented (e.g., knowing how to compute the square perimeter is the most important goal for the student) and thinks that making mistakes is useful for learning (e.g., "This mistake can help me understand why I did not compute the square perimeter well"). Furthermore, the student knows that making mistakes is not a problem for the mathematics teachers and that classmates are always willing to help those who make mistakes (i.e., an error-friendly environment has been established during mathematics classes, see Chapter 3). Therefore, the emotional regulation may change, becoming more adaptive (see section 3.1. of this chapter).

1.2. What happens when a student makes an error: Motivational regulations

Changes in emotional status following the error detection led to motivational regulations (Figure 2). As explained above, the emotional appraisal has a role in determining affective changes and causal attribution after making mistakes. Students who interpret an error as caused by uncontrollable causes may feel dissatisfied, and thus, may be discouraged from engaging in further learning activities or tasks (Zimmerman, 2009). According to the Cyclical Phases model proposed by Zimmerman (see Chapter 1), during the *self-reflection phase* (i.e., when students assess their performance according to received feedback), students' self-evaluative judgment and causal attribution are the two main sources of motivation. These sources of motivation are linked to important self-reactions, such as self-satisfaction (Zimmerman, 2009).

In facing a mistake, if the assessment of the situation, namely the emotional appraisal and the causal attribution patterns, is not adaptive, the student may be less motivated in persisting and adapting strategies to overcome the error. For instance, deactivating emotions, namely emotions that hinder the students' commitment to learning activities (such as hopelessness), are linked to a motivational decrease (Pekrun et al., 2010). In this phase of the learning from errors model (Tulis et al., 2016), emotional and motivational changes are closely related and affect each other reciprocally. The motivational process, for instance, precedes, fosters, and modulates emotions, and emotions include motivational components and influence motivation (Pekrun, 2006). Furthermore, the role of causal attribution is important as well: It guides both emotional and motivational processes and constantly influences how students perceive the error and react to it.

In the scenario described before, the student first experienced a negative appraisal and made internal, controllable causal attribution, which may have led to negative emotions, such as shame. However, thanks to the positive beliefs about making mistakes, and the perception of being in an error-friendly environment, the student regulated the emotions positively. Consequently, positive emotions sustained the student's motivation, and the student is now curious to discover why the mistake occurred.

1.3. What happens when a student makes an error: Cognitive and metacognitive processes

In the following step (Figure 2), emotional and motivational regulations are assumed to foster cognitive and metacognitive functioning. As shown in Chapter 1 (Box 1), cognitive processes encompass all the strategies used to transform and understand information. Metacognitive processes refer to all the higher-order functions aimed at controlling cognitive strategies (see Lajoie, 2008). Cognitive and metacognitive processes are particularly important in learning from errors. For instance, maladaptive strategies, such as suppression or

ruminations, may hinder the possibility of deeply understanding the mistake (Tulis et al., 2016). In the same line, a negative evaluation of the performance progress caused by receiving error feedback may increase the number of useless learning procedures adopted to solve the error.

According to Efklides and colleagues (2018), emotions and motivational regulation, as well as cognition and metacognition processes, are linked in an ongoing dynamic and create an interplay between these four self-regulated learning facets. On the one hand, adaptive and effective emotional-motivational regulations may increase the probability of sustaining useful cognitive and metacognitive processes. Negative emotions and low motivations, on the contrary, may lead to detrimental cognitive and metacognitive strategies (Tulis et al., 2016). On the other hand, cognitive and metacognitive processes affect subsequent emotions and motivation (Efklides, 2011).

Metacognitive activities, cognitive strategies, and learning behaviours are considered the final steps of the learning from errors model. Coming back to our example, the student's emotional reactions, as well as motivational changes, were adaptively regulated during the whole process. Therefore, a series of cognitive strategies aimed at reorganising the information and detecting the missing concept to compute the square perimeter is started. When the student understands the cause of the mistake and computes the operation correctly, she raises her hand again to give the right answer to the teacher.

Self-regulation processes are the core part of the learning from errors model, and only if these processes are adaptive students can effectively learn from mistakes. Furthermore, several individual features may affect the result of the process (i.e., learning successfully). In the next section, we present empirical findings that support the importance of reacting adaptively to errors and the relationship between adaptive reactions towards errors and individual features.

2. Adaptive reactions towards errors

The core part of the learning from errors model (Tulis et al., 2016) is characterised by self-regulation processes, which involve motivational and emotional regulations as well as cognitive and metacognitive changes. As outlined in the previously presented scenario, the student reacted positively to the teacher's error feedback. After making a mistake, the student felt positive emotions supported by the idea that errors are part of the learning process; positive emotions that led to maintaining stable motivation and useful cognitive strategies. In this case, we can say that the student's reactions towards the error were adaptive. The student would have reacted oppositely, feeling negative emotions, which may have resulted in decreased motivation and useless cognitive strategies. Adaptive reactions towards errors foster students' commitment to and effort in learning (Steuer et al., 2013) and may promote learning from errors.

Adaptive reactions towards errors refer to two separate self-regulation processes: *adaptive affective-motivational reactions towards errors,* namely, emotional and motivational regulation, and *adaptive action reactions towards errors,* namely, cognitive and metacognitive strategies. The former describes positive emotions and sustained motivation in performing the task after making mistakes. The latter is defined as the set of learning strategies and actions addressed to understand and overcome the mistake and thus encompass cognitive and metacognitive self-regulation strategies, referring specifically to the error (Dresel et al., 2013). As stated by Steuer and colleagues (2013, p. 197), adaptive reactions towards errors "are best conceptualised as a special class of self-regulated learning processes.".

The literature about adaptive reactions towards errors has been growing recently. Besides defining them theoretically, Dresel and colleagues (2013) developed and validated a questionnaire to assess these two reactions and further research demonstrated that they

represent two separate and distinct constructs (Grassinger & Dresel, 2017; Steuer et al., 2013; Tulis et al., 2018). Furthermore, Grassinger and Dresel (2017) argued that affective-motivation reactions are necessary but insufficient to foster action reactions towards errors. After administering the adaptive reactions towards error questionnaire (Dresel et al., 2013) to a sample of 479 German secondary school students during a class test (a situation in which mistakes are salient), they ran a latent profile analysis. The results revealed three different profiles of students based on their error reactions. More precisely, 47% of them showed a profile with high adaptive affective-motivational reactions and high adaptive action reactions to errors. These students reported feeling positive emotions and high motivation, as well as knowing which cognitive error-related strategies to adopt after making mistakes. Another part of the sample (44%) reported low adaptive affective-motivational and low adaptive action reactions towards errors. These students most likely do not maintain stable motivation and positive emotions after making a mistake. Consequently, their cognitive and metacognitive strategies may not be functional for overcoming the error. Finally, a very small group, 9% of the whole sample, showed high adaptive affective-motivational reactions and low adaptive action-reactions following errors. These students were probably highly motivated and felt positive emotions, but they were not able to find adaptive cognitive strategies after making mistakes.

Finally, another study (Grassinger et al., 2018) showed that affective-motivational reactions are linked to academic achievement via action reactions, pointing out the mediation role of cognitive and metacognitive regulation. This result is in line with the learning from errors model. However, more empirical findings are needed to support this relation.

3.1. Adaptive reactions towards errors and individual characteristics

Maintaining high motivation, positive emotions and activating efficient metacognitive processes after making mistakes also depends on personal characteristics and intra-individual variables, such as personal achievement goals, academic self-concept, and error beliefs (Figure 2; Grassinger & Dresel, 2017; Steuer et al., 2013; Tulis et al., 2018). In this section, we describe the role of beliefs about errors because they will be further investigated in the empirical part. For more details on the other two personal features, see Box 2.

Box 2. Achievement goal and Academic self-concept

Personal achievement goals have been defined as the purpose that pushes students to engage in learning and achievement activities (Elliot & Hulleman, 2017). According to this theory, students engage in learning activities for two main scopes: deeply understand and know the subject (i.e., mastery goal) or outperform others and demonstrate competencies (i.e., performance goal). In addition, both mastery and performance goals are divided into approach and avoidance orientation. The approach dimension refers to the willingness of pursuing the task to succeed on it. Differently, the avoidance dimension refers to the tendency to prevent performing a task, and it is related to the fear of failure (Elliot & McGregor 2001; Elliot & Hulleman, 2017).

Achievement goal theory has been considered a lens to understand why some students react positively to failure, and others do not (Steuer et al., 2013). Steuer and colleagues (2013) and Tulis and colleagues (2018) showed that personal mastery goal orientation is positively related to adaptive affective-motivational and action reactions towards errors. Grassinger and Dresel (2017) also partially corroborated this result, finding that performance-avoidance goal is negatively associated only with affective-motivational reactions towards errors but not with action reactions.

Academic self-concept, the perception of being able to accomplish achievement activities (e.g., Sewasew & Schroeders, 2018), is another important personal feature that may impact the adaptive reactions towards errors. Academic self-concept is associated with success in education (e.g., Marsh et al., 2018) and may play a role in determining the causal attributional process which follows making mistakes. For instance, a student with a low academic self-concept may make stable and internal causal attributions, such as a lack of intelligence. On the contrary, students with high academic self-concept may interpret errors resulting from external or unstable causes, such as a lack of studying (Grassinger & Dresel, 2017). A correlational study showed that students with higher academic self-concept had a higher level of affective-motivational reactions than students with lower academic self-concept (Grassinger & Dresel, 2017). In line with that, Steuer and colleagues' (2013) findings supported the positive relationship between academic self-concept and the two adaptive reactions towards errors.

3.1.1. Positive beliefs about errors

Positive beliefs about errors are an individual characteristic that received attention in the literature related to the learning from errors process (Tulis et al., 2016). Beliefs about errors is a concept that has been recently developed (Tulis et al., 2018) and has been linked to the learning from errors process and to the other personal features.

Beliefs are broadly defined as internal ideas, premises, and thoughts that people consider true (Richardson, 1996). Beliefs are important and meaningful for people and sustain their actions and behaviours. Furthermore, students' beliefs affect several learning-related choices and decisions, such as the kind of tasks students choose, how much effort they put into achieving the task, and their standards in judging their failure or success in accomplishing the task (e.g., Murphy & Mason, 2006). In the same line, positive beliefs about errors are conceptualised as the idea that errors are important parts of learning, and thus, they may increase the possibility that a student faces the error by activating adaptive self-regulation strategies (Tulis et al., 2018). For instance, students who believe that errors are important for their learning showed more positive emotions than students who do not hold these beliefs (Tulis & Ainley, 2011).

Tulis and colleagues (2018) recently conceptualised the positive beliefs about errors construct and validated a questionnaire to assess these beliefs. More precisely, the authors argued that holding the idea that making mistakes is a learning opportunity instead of a sign of failure is an important facet of students' capability to deal with errors. Therefore, error beliefs should be considered when the students' reactions toward errors are analysed and studied. The authors demonstrated that positive beliefs about errors are distinguished from affective-motivational and action-reaction. Furthermore, they analysed the relationship between these three variables and other personal features, namely academic self-concept and mastery goal orientation. Their result showed that positive beliefs about errors mediate the

relationship between academic self-concept and mastery orientation and both adaptive reactions towards errors. Therefore, beliefs about errors as proximal predictors of individual reactions toward errors, whereas academic self-concept and mastery orientation are distal predictors.

4. Conclusion

This chapter focused on the central part of the learning from errors model proposed by Tulis and colleagues (2016). The self-regulated processes activated by error detection have been described, explaining in depth the role of emotions, motivations, causal thinking, and cognitive and metacognitive strategies. Furthermore, empirical findings on how personal characteristics (e.g., academic self-concept, achievement motivation, and error beliefs) affect learning from errors have been presented.

Further empirical findings that support the theoretical model of learning from errors (Tulis et al., 2016) are needed. For instance, little is still known about the relationship between the two adaptive reactions towards errors as well as their link with learning outcomes. In addition, only one study analysed the role of error beliefs in promoting the learning from errors process (Tulis et al., 2018). Furthermore, most of the studies presented above were carried out in the German secondary school context and, to the best of our knowledge, to date, there are no studies that have applied the learning from errors model in other cultural contexts and school grades.

Besides explaining intra-individual processes, the model elaborated by Tulis and colleagues (2016) also included contextual features that may impact learning from errors. In the next chapter, we will describe the perceived classroom error climate. In addition, we expand the Tulis and colleagues' model (2016) by presenting research on teachers' error-handling practices that may promote an error-friendly environment.

Chapter 3

Relational features that affect the learning from errors process

1. The role of errors in learning at the relational level

The relational level of analysis encompasses the interactions within a group and between individuals that influence learning (Mercer & Littleton, 2007). How students react to errors, namely which kind of emotions, motivational regulations, and cognitive-metacognitive processes they activate while facing an error, also depends on the characteristics of social interactions and the environment in which the error occurred.

The importance of considering the relational aspects of mistakes is derived from the idea that errors are not only objective events that trigger some student reactions, but they also have a social connotation (Billett, 2012) conveyed within social relationships. The PISA survey results about students' well-being (OECD, 2019) showed that 56% of the students in OECD countries reported that they *are worried about what others think* about them when they err. Being negatively judged by other people is a consequence related to the social connotation of making mistakes. These consequences mostly depend on how errors are framed in the learning context (e.g., Steuer et al., 2013) within the relationship established in the classroom.

The teacher-student relationship is one of the most significant social interactions in school. The meaning of errors and their use in the learning process may vary based on how errors are interpreted and perceived within the teacher-student relationship. Teachers can provide students with supportive feedback to promote their understanding of misconceptions (e.g., Hattie, 2009) and help students develop their points of view by encouraging dialogue and argumentation (e.g., Greco et al., 2017).

Teachers also have a pivotal role in establishing a supportive and positive climate through teaching practices (e.g., Pianta & Hamre, 2009; Wang et al., 2020). Several studies have highlighted how teachers can manage the aspects of the classroom climate differently, such as emotional aspects (i.e., classroom emotional climate, Reyes et al., 2012) or motivational classroom structure (e.g., Meece et al., 2006; Murayama & Elliott, 2009). In the same line, teachers may establish an error-friendly environment by dealing with students' errors supportively. The idea of the importance of promoting an error-friendly environment is derived from the literature on error culture in organizational settings. Several researchers demonstrated that a positive error culture, characterised by actions and behaviours aimed at including, analysing, and understanding errors, fosters learning and positive outcomes (e.g., increasing performance; Dyck et al., 2005; Frese & Keith, 2015; Weinzimmer & Esken, 2017).

The research on classroom climate and organizational culture reaffirms that social relationships are the "space" in which specific error meanings are conveyed. Furthermore, the practices adopted to deal with mistakes have a key role in creating a positive and supportive climate. A growing body of research provides empirical findings of the perceived error climate, namely, a facet of classroom climate related to students' errors. In the next two sections, these results will be presented along with research results on the role of teachers in promoting error-friendly learning environments.

2. The perceived error climate

Steuer and colleagues (2013) defined the positive perceived error climate in the classroom as "the evaluation and use of errors as integral elements of the learning process in the social learning environment of the classroom" (p. 198). The perceived error climate, a classroom error-related characteristic, is assumed to affect the learning from errors process by

influencing the way in which students react to errors (i.e., if students perceive to be part of an environment in which there is a positive error climate, they should react more adaptively to their mistakes).

Perceiving a positive error climate means that students appraise errors as helpful for learning, and thus, making mistakes is accepted, and negative teachers' and classmates' reactions are not tolerated. A positive error climate is assumed to influence students' positive emotions, such as enjoyment, satisfaction, and pride (Tulis, 2013), their motivation to achieve, and their cognitive and metacognitive processes (e.g., Tulis et al., 2016). On the contrary, a negative perceived error climate is characterised by a mistake avoidance orientation because errors are negatively evaluated and may provoke hostile and discouraging reactions in teachers and classmates.

2.1. The dimensions of the perceived error climate

Steuer and colleagues (2013) conceptualised the perceived error climate as divided into eight subdimensions, and the authors developed a questionnaire to assess it. Theoretically, the eight subdimensions are divided into three groups, each of which has a specific focus: teachers, classmates, and the use of errors.

The first group comprises four subdimensions related to the teacher's activities, behaviours, and affective reactions after students' mistakes. The *Error tolerance by the teacher* refers to the extent to which teachers express an avoidance attitude towards errors by, for instance, explicitly saying that error should be avoided while completing a task. The *Irrelevance of errors for assessment* concerns assessing errors with low evaluation during learning activities. During performance activities (e.g., testing the learning level of students), evaluation is typically used, and thus, a negative interdependence could emerge between errors and evaluation (i.e., the more the errors, the less the value of the evaluation). Using evaluation during learning activities and mixing learning and performance activities may be

detrimental to students' motivation (Meyer et al., 2006). The *Teacher support following errors* refers to the strategies teachers adopt to correct the error patiently, to help and support students after the mistake. The *Absence of negative teacher reactions* concerns how teachers avoid showing negative affective reactions after the error, such as anger or disappointment.

The group focused on the classmates comprises two dimensions: *Absence of negative classmate reactions* and *Taking the error risk*. The former refers to the extent to which classmates react negatively to another student's mistakes. Classmates' relationships are essential characteristics of a positive and supportive climate in the classroom (e.g., Zander et al., 2014). Adverse reactions, such as laughing or making fun of others, may promote feelings of shame and error-avoidance attitudes. Taking the error risk refers to the perception that it is possible to say something that might be wrong without being negatively judged. This feeling depends on the trust that the students have in their classmates and their teachers.

Finally, the last group of subdimensions comprises the *Analysis of errors* and the *Functionality of errors for learning*. These two subdimensions are linked to the way in which errors are included in the learning process (i.e., if errors are analysed in detail or avoided during the learning activities) and presented as tools to promote learning (i.e., if errors are presented as beneficial for the learning process or not).

These eight subdimensions constitute, in concert, the general error climate perceived by the students. The error climate has been conceptualised as the individual perception of an environmental feature. For this reason, it has been assessed using a self-reported questionnaire, the error climate questionnaire, developed by Steuer and colleagues (2013).

2.2. Assessing the perceived error climate

The error climate perceived in the classroom was assessed for the first time with a self-reported questionnaire on a sample of 1,164 German secondary schools in a study aimed at validating the theoretical concept (Steuer et al., 2013). The questionnaire comprises 31

items, four for each subdimension (except for the *Taking the error risk*, which has only three items). The authors found that the subdimensions were all distinguishable but closely interrelated, and all the subscales showed good internal reliability. With a series of confirmatory factor analyses (CFA), the authors tested four theoretical models: the eight-factor structure model, the three-factor structure model (representing the three groups based on the teacher, classmates, and the use of error), the single-factor model and a superordinate factor model (comprising the eight dimensions and a higher-order factor which encompasses the eight dimensions). The results showed that the eight-factor structure fitted the data well, as well as the superordinate factor structure, which is a representation of students' global perception of the error climate in the classroom.

Steuer and colleagues (2013) found that within classrooms the perception of the perceived error climate was homogenous (i.e., ICC2[1] = .69 – .90), while it changed significantly between classrooms (i.e., ICC1[2] = .10 - .31; $p < .001$). They also demonstrated that the unidimensional model was appropriate to assess the perceived error climate at the between classroom level because

it corresponds to the superordinate factor model measured at the within classroom level. These results provided important methodological information to assess the perceived error climate

properly, as they indicate that the perception of error climate is shared among students in the same classrooms. Besides assessing how students individually perceive the classroom climate (i.e., within-level), it is therefore important to understand how shared perceptions of the error climate vary across classrooms (i.e., between-level) and how this variability may affect

[1] ICC2 = intraclass correlation 2 indicates the reliability of the classroom mean ratings (measure of the reliability of the measurement of a contextual characteristic via several individual perceptions, with values above .70 indicating a good reliability).
[2] ICC1 = intraclass correlation indicates the proportion of the variance explained by the between level among the total variance.

students' outcomes. Thus, to investigate the significance of error climate for student learning, both levels of analysis should be considered (see also Käfer et al., 2019).

2.3. Perceived error climate, adaptive reactions towards errors and achievement

Besides testing the validity of the error climate construct and the perceived error climate questionnaire, Steuer and colleagues (2013) analysed its relationship with the adaptive reactions towards errors (Dresel et al., 2013, see Chapter 2). More specifically, they found that perceived error climate as an overall construct (i.e., the superordinate uniform factor) was related to more adaptive affective-motivational and action reactions towards errors. Narrowing the lens, they also tested the relations between the eight subdimensions and the students' reactions. They showed that the Error tolerance by the teacher, Teachers support following errors, Functionality of errors for learning, and Taking the error risk subdimensions were associated with more adaptive affective-motivational reactions. Teacher support following errors, Absence of negative teacher reactions, and Analysis of errors during the lesson subdimensions were associated with more adaptive action reactions. Teachers' positive reactions and support, as well as including errors in the learning activities, were the key factors in boosting students' adaptive reactions towards errors.

In another study with 1,525 students from 90 classrooms in German secondary schools, Steuer and Dresel (2015) found small but significant correlations between error climate and students' achievement in mathematics, both at the within and between classroom levels. Although the authors did not test causality in their study, they argued that it is possible to assume the perceived error climate affects achievement. The two dimensions of perceived error climate that were especially important in affecting students' achievement were Analysis of errors and the Functionality of errors for learning. An interpretation could be that only if the errors became part of the learning process and if they are presented as a tool for learning

(i.e., a positive error climate), the students can learn from them and, in turn, reach better achievements (Steuer & Dresel, 2015).

This result was supported by Grassinger and colleagues' (2018) findings. In a longitudinal study involving 2,092 German fifth- and eighth-grade students, the authors found that perceiving a positive error climate was associated with more adaptive affective-motivational reactions and more adaptive action reactions. In addition, action reactions were related to higher academic achievement (assessed by using students' grades obtained at the end of the year in mathematics, English as a foreign language, and German). This result showed that perceived positive error climate was related to higher students' achievement via more adaptive reactions towards errors. More precisely, the findings showed a sequential mediation effect in which more adaptive affective-motivational reactions (first mediator) were associated with more adaptive action reactions (second mediator).

Finally, Steuer and colleagues (2013) provided results on the differentiation between the perceived error climate and the classroom goal structure (e.g., Meece et al., 2006), which is another feature of the classroom setting that may overlap with the perceived error climate. Classroom goal structure refers to the students' perception of goal-related attitudes and messages established and used in the class. This structure (which focuses on either mastery or performance) may lead the whole class to adaptive or maladaptive motivational and behavioural outcomes. Although classroom goal structure presented some facets related to making mistakes (i.e., goal-related messages may include positively handling errors or avoiding making mistakes), perceived error climate refers explicitly to the error at hand. In line with this, perceived error climate has been shown to affect adaptive reactions towards errors above and beyond classroom goal structure (Steuer et al., 2013). This result supported the importance of analysing the perceived error climate as a contextual feature that may play a specific role in promoting students' adaptive reactions.

To sum up, a growing body of research demonstrates that the error climate is a specific error-related feature that influences the general learning process because it is related to students' reactions towards errors as well as to learning outcomes. These empirical findings support the learning from errors model (Tulis et al., 2016) by showing that external variables affect the self-regulated processes triggered by error detection.

Recent research has shown that establishing an error-friendly environment depends on how teachers handle errors in their classrooms. Teachers have a pivotal role in managing the classroom, including error-related activities. In the next section, we will expand the learning from errors model proposed by Tulis and colleagues (2016) by adding another contextual variable, namely teachers' error-handling strategies.

3. The role of the teacher in fostering an error-friendly classroom environment

Through their teaching practices and the message shared during classes activities, teachers can promote a positive classroom climate (e.g., Jennings & Greenberg, 2009), mastery-oriented classroom goal structure (e.g., Bardach et al., 2020), as well as students' achievement motivation (e.g., Thoonen et al., 2011; Maulana et al., 2016), well-being (Guo et al., 2020; Mælan et al., 2019), and learning outcomes (e.g., Bryce et al., 2019).

Some studies have focused on teachers' supportive error-handling strategies to promote students' motivation, achievements, and perceptions of an error-friendly classroom environment. For the sake of clarity, we present different empirical findings and divide them into three categories. The first one comprises all the research based on students' perceptions assessed through self-report measures. The second category comprises experimental studies, whereas the third encompasses research based on videotaped lessons combined with quantitative (i.e., students' self-report questionnaires) or qualitative data (i.e., teachers and students' interviews). Some of the research presented in this section has examined the

connection between teachers' error-handling practices and their beliefs. The last part of this chapter will explore teachers' beliefs about errors.

3.1. Empirical findings based on students' self-report measures

Most of the studies that assessed students' points of view about their teachers' practices have been carried out in German and Swiss schools (e.g., Kreutzmann et al., 2014; Spychiger et al., 1998; 2006). We summarise here the results of two studies (i.e., Heinze et al., 2012; Käfer et al., 2019) that assessed the students' perceptions through a self-report questionnaire developed by Spychiger and colleagues (1998; 2006). This questionnaire comprises 27 items that refer to three underlying factors: teacher behaviour in error situations, the use of errors as learning opportunities, and emotional aspects of error situations.

In the study carried out by Heinze and colleagues (2012) with a sample of 1,674 secondary school German students, the authors proposed a four-factor model of the Spychiger and colleagues (1998; 2006) questionnaire. More precisely, they disentangle the factor *Teacher behaviour in error situations* into two different factors: *Affective aspects of the teacher behaviour in mistake situations* and *Cognitive aspects of the teacher behaviour in mistake situations*. The other two factors were recalled by authors as S*tudents' individual use of errors for learning* and *Fear of making mistakes* (see also Heize & Reiss, 2007). The result of this study we will consider here was that the cognitive and affective aspects of teachers' behaviour have a particular effect on students' use of errors and fear of making mistakes. On the one hand, cognitive aspects of teachers' behaviour directly affect how students use errors as a learning opportunity and, at the same time, increase the students' fear of making mistakes. On the other hand, affective teachers' support reduced students' fear of making mistakes. These findings revealed that the two parts of teachers' behaviour (i.e., affective and cognitive) needed to be separated to analyse the various supports teachers may provide to students who made mistakes. Even though the effect of these two variables on fear of making

mistakes needs to be examined further, this study highlighted the relevance of examining students' perceptions of teachers' behaviour and its impact on students' personal approaches to errors.

Käfer and colleagues (2019), using data from DESI assessment (*Assessment of Student Achievements in German and English as a Foreign Language*; DESI-Konsortium, 2008), analysed self-report questionnaires of 5,266 German secondary school students. Their aim was to understand which dimensions of dealing with mistakes (adapted from Spychiger et al., 1998) were associated with students' motivation to achieve and their achievement in English as a foreign language. They found that positive teachers' attitudes towards mistakes, teachers' responses to students' mistakes, and students' perceptions of the functionality of errors for learning were positively related to students' achievement and motivation at the within-level. Furthermore, at the between-level, students' shared perception of an error-friendly environment (i.e., characterised by positive teachers' attitude towards mistakes and teachers' responses to students' mistakes) was related to students' motivation above their individual perception. These results showed the importance of extending the study of error-related variables to other domains than mathematics, as well as the importance of considering both levels of analysis (i.e., individual and classroom level) to disentangle the effect of students' individual and shared perceptions of teachers' behaviour on dispositional variables.

These two correlational studies found that teachers' error-related reactions and behaviour refer to several dimensions that influence students' perceptions of being in an error-friendly environment, as well as learning-related variables such as motivation.

3.2. Empirical findings based on experimental design and teachers' training

This section presents the findings of experimental studies which manipulated the teachers' error-handling strategies. The first two studies (Heinze & Reiss, 2007; Rach et al., 2013) implemented training for teachers to change their error-handling practices. In the other

two (Heemsoth & Heinze, 2016; Lee, 2020), the manipulation occurred directly in the learning contexts.

In Heinze and Reiss's research (2007), teachers of 29 German secondary school classrooms took part in training at the beginning of the year. Teachers were divided into two conditions. In the experimental condition, teachers learned strategies to increase students' reasoning in mathematics and how to use mistakes fruitfully in mathematics classes by including them in the learning activities. In the control condition, teachers took part in training on reasoning in mathematics only. Two months after the training, all the students took part in a reasoning test and filled in a questionnaire about their perceptions of teachers' error-handling strategies in the classroom (Spychiger et al., 1998). The results showed that students in the experimental group perceived their teachers as more emotionally supportive than students in the control group. As for the test on mathematics reasoning, students in the experimental condition outperformed their peers in the control condition.

The results from Rach and colleagues (2013) corroborated Heinze and Reiss's (2007) findings. Teachers from 32 German classrooms were divided into three conditions. In the first condition, teachers took part in training about the potential use of errors for learning. In the second condition, the training was the same, but teachers also were provided with specific practical materials for students. More precisely, these materials were aimed at encouraging students to reflect on their errors during mathematics lessons. The third group was a control group in which teachers did not attend any course. The Spychiger and colleagues (2006) questionnaire was used to assess students' attitudes towards error-handling before and after the intervention. The results showed that in the two experimental conditions (i.e., training on error-handling strategies and error-handling strategies plus cognitive materials), students perceived teachers as more supportive. Furthermore, students in experimental groups reported lower levels of fear of making errors than the students in the control group. There were no

significant differences between the two experimental groups in how students perceived their teachers and used errors as an opportunity for learning. According to the authors, this result indicated that providing teachers with additional materials to support students in using errors fruitfully did not enhance teaching strategies aimed at including errors in learning and supporting students in using errors fruitfully.

Unlike these previous studies, Heemsoth and Heinze (2016) did not train teachers for their experimental study but manipulated their variables during the class interventions (i.e., 11 mathematics lessons carried out by two researchers' collaborators). German secondary school students were divided into two conditions: error-centred condition and solution-centred condition. In the first, students were encouraged to reflect on their misconceptions during the learning activities, whereas, in the second, students were asked to consider only the error's solution. The study aimed to understand the impact of reflecting on mistakes on self-regulated learning processes. Thus, the researchers measured students' procedural and conceptual knowledge before, immediately after, and 6 weeks after the intervention. Results showed that students who attended classes in which the learning strategy was error-centred (they were encouraged to reflect on their mistakes) outperformed students of the control groups in the post and follow-up tests.

Lee (2020) tested the effects of an experimental approach focused on students' mistake reflection to foster learning. A sample composed of two university classes was divided into two conditions. In the experimental group, a learning-from-mistakes approach was used during the lesson. This approach consisted of two moments. Students were encouraged to understand their mistakes alone and discuss them openly with their teachers or classmates. Furthermore, students took part in a separate section in which they were told that making mistakes is useful for learning to foster students' positive attitudes towards errors. In the control group, a traditional classroom instructional approach, based on receiving correct

responses after making mistakes, was used. The authors measured knowledge and skills before and after the treatment. Results indicated that the experimental group, which was encouraged to use the learning-from-mistakes approach in a psychologically safe environment, outperformed students in the traditional class at the post-test.

The findings of the above-mentioned experimental studies have important implications. First, if combined with other data demonstrating the value of reflecting on mistakes (e.g., Kapur, 2009), they may imply that an error-centred lesson structure may promote higher learning outcomes. Second, teacher training findings revealed that raising teachers' awareness of error-handling strategies may be effective in adjusting their teaching practices linked to mistakes, which may encourage a change in students' perceptions and improvement of learning outcomes.

3.3. Empirical findings based on analysis of videotaped lessons

In this section, findings of studies that used a methodology based on analysing videotaped lessons to understand teachers' error-handling practices in the classroom context are presented. In the study carried out by Santagata (2004), 30 Italian and 30 U.S. mathematics teachers were observed during lessons. Three kinds of error-related responses emerged from the observations: Mitigating responses (e.g., "You are almost there!", "Try again!"), aggravating responses (e.g., "Bad mistake!", "Are you kidding or are you sleeping?"), and neutral responses (i.e., all those that did not fall into the above categories). Several differences were found between the two groups of teachers. Italian teachers used more aggravating answers (35%) than mitigating ones (5%), whereas U.S. teachers used more mitigating (38%) than aggravating (2%) answers. According to the author, differences in the mathematics lesson structure between the two countries may be an explanation. In fact, in the U.S., students and teachers privately discussed a larger percentage of the mistakes (39%) than in Italy (3%). In Italy, 85% of the lesson is devoted to teaching activities and only 10% to

individual student exercises. Furthermore, in the Italian sample, 47% of errors were corrected on the blackboard or in a public situation (i.e., in front of the whole class). On the contrary, in U.S. mathematics lessons, 62% of the time is spent on whole-class instruction, whereas 38% is spent on students' individual exercises, and only 8% of errors are corrected on the blackboard.

Another explanation is based on how cultural beliefs about learning, teaching, and students' role, inform teachers' error-related practices. Combining observational results with qualitative data from focus groups, the author found that Italian students and teachers shared the same idea about "being a student", namely a person responsible for his/her learning and who needs to be pushed to perform the work that is necessary to learn. In the same line, U.S. teachers' error-handling strategies are consistent with their shared idea of the student as a "child inherently good" (p. 159) whose self-esteem should be preserved while facing mistakes. The author pointed out that teaching is based on classroom practices informed by shared cultural beliefs.

Analogue results have been found by Schleppenbach and colleagues (2007), who compared U.S. and Chinese teachers' error-handling practices. By analysing 44 videotaped lessons, the authors provided other evidence about how teachers of different countries deal with students' mistakes and which beliefs about errors teachers hold. They found that teachers in the two countries showed different error-handling strategies. Chinese teachers asked more questions about errors, thereby making students reflect more on the mistakes. Chinese teachers redirected the discussion about the error more often than the U.S. teachers and encouraged students to work on their mistakes. U.S. teachers made statements to highlight the errors (i.e., "This is not correct") or gave the correct answer significantly more often than the Chinese teachers.

The observational data were combined with interview data, which provided insights into teachers' beliefs on mistakes. Both sample groups considered errors as natural aspects of learning because errors can help teachers and students. Moreover, teachers of both groups believed that some practical activities might promote efficient use of mistakes, such as reviewing errors to help students make fewer mistakes and remember the right answers or working on students' mistakes during the lesson. These beliefs were linked with some practices teachers said they adopted with the aim of creating a risk-free environment. However, only Chinese teachers made statements on the importance of making errors during the videotaped lessons, and thus, they openly expressed this belief to their students. Moreover, only Chinese teachers stated clearly that they created the conditions to make students err in order to use the errors as a steppingstone for learning. These findings stressed the idea that observed error-handling strategies mirror teachers' beliefs about mistakes and cultural differences.

Switching the focus to students' perspectives, Tulis (2013) carried out a study in the German context combining observational data on teachers and self-report questionnaire data from students. In this study, Tulis videotaped 10 teachers during mathematics lessons and asked the students to fill in a questionnaire based on Spychiger and colleagues (2006) and Rybowiak and colleagues (1999) scales. First, the author observed three types of error-handling strategies: maladaptive, neutral, and adaptive. More precisely, maladaptive responses to students' errors were: (a) ignoring mistakes, (b) criticising students, (c) redirecting the question to another student, (d) humiliating/laughing and (e) showing disappointment. On the contrary, the adaptive responses to students' errors were: (a) discussion with the whole class, (b) correction by the student, (c) waiting, (d) emphasising the learning potential of errors and (e) preventing negative reactions from classmates. The neutral response was (a) the teacher directly correcting the error. The adaptive responses were more

frequent than the maladaptive, and maladaptive responses were more common in those classes where students perceived the teacher's intolerance of error. Second, the author found that the way teachers dealt with students' mistakes influenced the students' perception of the error and the students' domain-specific emotions. Students showed different attitudes toward errors based on how teachers handled the mistake in class, and the teachers' tolerance of errors also had a long-term effect on student attitudes toward (learning from) errors. These findings demonstrated a relation between teachers' error-handling strategies and students' attitudes towards the idea of mistakes.

Finally, Ingram and colleagues (2015) analysed 22 videotaped lessons through the conversational analytic approach, a method that examines how participants design their communicative turns while interacting to achieve a specific goal (in this case, correcting mistakes). Although the authors used a different methodology than the previous studies to analyse the data, they found similar results. Indeed, their findings highlighted that after students' mistakes, three possible interactional trajectories emerged: (1) the teacher directly corrects the errors at hand, (2) the teacher does not consider the error, and thus, no evaluation or correction of the error occurs, (3) the teacher initiates repairing the students' errors, asking additional questions, and supporting students to give the correct answer. The most common trajectory was the last in which teachers offered different opportunities for the student to correct the errors. According to the author, this kind of response to students' mistakes enabled them to take advantage of their mistakes by reflecting on and understanding them. On the contrary, strategies of avoiding mistakes or negatively evaluating the error do not highlight the pedagogical facet of making mistakes.

The studies based on videotaped lessons point out two critical findings. The first concerns how teachers usually deal with students' errors. It is a typical result that teachers implement more *adaptive* or *neutral* strategies than *maladaptive* or *aggravating* strategies (to

put it in Tulis and Santagata's terms). The second result relates to the benefit these adaptive error-handling strategies had on students. Ingram and colleagues (2015) and Tulis (2013) reported that adaptive strategies promoted students' positive perceptions and yielded more productive dialogical exchanges. This is in line with the results shown by experiment-based studies (e.g., Heinze & Reiss, 2007; Rach et al., 2013), highlighting that promoting supportive teachers' error-related strategies led to improvements in students' affective (i.e., fear of making mistakes) and performance aspects.

Overall, besides the methodology used, teachers' error-handling strategies resulted in having a pivotal role in determining an error-friendly environment and promoting students' learning from errors. According to Santagata (2004), teachers' practices (e.g., error-handling strategies) result from an interplay between teachers' beliefs and education system structural features, such as the lesson organization (e.g., solving exercises at the blackboard). In the next section, we analyse the role of teachers' beliefs in determining teachers' practices.

3.4. Teachers' beliefs about errors and their association with teaching practices

Beliefs are defined as people's understandings, premises, or propositions about aspects of the world that are strongly considered true (Richardson, 1996). In the same line, teachers' beliefs could be broadly defined as meanings they give to a learning phenomenon, such as subject matter, learning trajectories, or teaching (Calderhead, 1996). According to some scholars, teachers' beliefs are part of a more complex system of mental structures (i.e., conceptions), which are culturally defined and drive interpretations of events, people, or interactions (Pajares, 1992; Thompson, 1992) as well as filter experience and frame situations and problems (Fives & Buehl, 2011). Teachers' beliefs are multifaceted, interconnected, dynamic, and susceptible to change (Brown, 2004). Furthermore, several studies claim that teachers' beliefs determine how they consider their teaching role (e.g., Macnab & Payne,

2003), influence their change process, and drive their classroom activities (i.e., their teaching practices; Richardson, 1996).

Bray (2011) found that teachers' beliefs about using errors in the learning process affect how teachers structure class discussions when errors happen. For instance, the author found that teachers who preferred to avoid discussing mistakes during the learning activities believed sharing students' errors publicly would be embarrassing for students or confuse them. On the contrary, teachers who believed that errors provided learning opportunities, both for the individual and for classmates, focused the discussion on students' mistakes.

Nevertheless, teachers may hold multiple and conflicting beliefs about some aspects of their job or role, and thus beliefs may be neither univocal nor consistent (Fives & Buehl, 2011). In the same vein, it has been shown that sometimes teachers' error-related practices are not consistent with their beliefs (Empson & Junk, 2004). These inconsistent results reflect the lack of agreement in the literature about the relationship between beliefs and practices. As argued by Buehl and Beck (2015), it is not still clear if teachers' beliefs build practices or if practices predict beliefs. Some authors argued that teachers' beliefs and practices have a complex relationship through which they reciprocally influence one another (e.g., Basturkmen, 2012; Richardson, 1996; Thompson, 1992).

According to Santagata (2005), a direct link between teachers' beliefs and practices is not always possible. Teaching is a means to socialise students to more general cultural values and social norms. Furthermore, teacher practices are also informed by shared routines as well as by education system structural organisation. For instance, in Santagata's (2004) research, the difference between Italian and U.S. teachers' error-handling strategies relied on the difference in teachers' beliefs (e.g., Italian teachers shared the belief that students should be pushed to work) and on the structural features of the lesson (e.g., Italian mathematics classes are based on blackboard exercise). The role of structural education system features (i.e.,

evaluation system) in determining the errors' meanings and the possibility to learn from errors will be the centre of the next chapter, which focuses on the cultural level of analysis.

4. Conclusion

Overall, the empirical findings presented in this chapter showed that perceiving a positive error climate fosters more adaptive reactions towards errors (i.e., affective-motivational and action reactions) and improved learning outcomes. Furthermore, it has been shown that teachers play a key role in creating an error-friendly environment by handling errors positively. Finally, in broadening the focus, it has been highlighted that teachers' error-handling practices could be, to some extent, linked to their beliefs about learning-related topics.

Nevertheless, further empirical results are needed. Indeed, only a few studies (e.g., Grassinger et al., 2018) have tested whether perceiving a positive error climate influences adaptive reactions towards error. In addition, this relation has been tested without considering other variables, such as error beliefs, which have been shown to affect individual reactions towards errors (Tulis et al., 2018). Furthermore, as already stated at the end of Chapter 2, research on the learning from errors model, as well as on perceived error climate, has been carried out only in the German secondary school context. Results on the applicability of the construct of the perceived error climate in other contexts and at other school levels have not been provided yet.

As for the role of the teachers, only a few studies have empirically tested the effect of adaptive error-handling strategies on students' perceptions of being in an error-friendly environment. Furthermore, none of the empirical or observational studies presented in section 2 has measured the perception of a positive error climate through Steuer and colleagues' (2013) instrument, which showed excellent psychometric properties. Finally, little attention has been

paid to teachers' beliefs related to students' errors, and their relationship with practices needs to be investigated further.

Chapter 4

Cultural values and education system features related to errors

1. The role of errors in learning at the cultural level

The cultural level described by Mercer and Littleton (2007) refers to the social norms and cultural values shared in society that may influence the learning process. These norms and values are conveyed by social institutions, like education systems. Education systems aim at educating new citizens and shaping people's ideologies by transmitting, for instance, ideas about learning goals, pedagogies, expectations about students' performance, and evaluation strategies (Butera et al., 2022; Mercer & Littleton, 2007).

In neoliberal societies, competitive ideologies, characterised by competitive values (e.g., meritocracy) and norms (e.g., productivity), are transmitted throughout generations by the education system (Butera et al., 2022). According to Butera and colleagues (2022), education systems convey these ideologies through structural tools, such as norm-referenced assessment and tracking, and through teachers' practices that may promote a competitive classroom climate. Furthermore, in the last two decades, school effectiveness and accountability have become more central in educational system development (OECD, 2013a), and educational reforms in the 21st century have relied on improving those aspects of schools (Figlio & Loeb, 2011). Figlio and Loeb (2011) defined school accountability as the process of assessing school effectiveness based on students' performance measures. The need to assess education systems is due to the increasing request for effectiveness, quality, and equity in education to meet economic and social needs. The national (e.g., INVALSI in Italy) and international (e.g., PISA, for OECD countries) programs to assess education systems are the

primary expression of the increased attention on measuring students' outcomes to measure school efficiency (OECD, 2013a).

Competition, effectiveness, performance, and accountability may have led to overestimating the importance of performance. According to some authors (Darnon et al., 2009; Dornbush et al., 1996), this overestimation is in line with the selective function of education systems, which aim is to sort students based on their performance level and divide them into different social positions. Besides this one, educational systems fulfil the educational function that aims at providing students with education, knowledge, and skills. Education systems are therefore based on structural features that allow the fulfilment of these two functions. In particular, the focus on students' performance is closely related to the use of normative grading assessment, one of the most common in the OECD countries (OECD, 2013b).

In such a performance-oriented culture, errors may become a sign of failure instead of a useful way to improve learning because they highlight a decrease in students' performance. Indeed, the more the errors, the lower the performance and the evaluation obtained. Therefore, the social pressure on performance, and thus the use of normative grading, may have detrimental effects on the possibility to consider errors positively. In this context, the role of teachers is extremely important because they not only influence students and classroom climate with their teaching practices (see Chapter 3) but also socialise them to socio-cultural rules and norms while teaching (Butera et al., 2021). Therefore, it is crucial to understand the role of teachers in presenting errors as a springboard for learning while preparing students to achieve the best result, assessing their performance frequently, and comparing them with other classmates. The next sections describe the characteristics of evaluation and normative assessment, their negative impact on learning and their link with students' errors. Then, the role of evaluation as a tool for reproducing social norms will be considered.

2. Evaluation and assessment: definition, characteristics, and effect on students' learning process

Evaluation at school is the practice of using assessment information to judge the value of learning activities and outcomes (e.g., a mathematics test) or academic careers (e.g., the learning development and improvements reached by a student during the school year). As Brookhart (2004) argued, evaluation differs from assessment because assessment is the activity of collecting information about something (e.g., students' performance) for a certain purpose (e.g., comparing different students' performances). In other words, using a simple example made by the author: "If you give a midterm exam and a student scores 64 per cent, that is an assessment. If you use that information to conclude that your student should come to see you get extra help or remedial assignments, that is evaluation." (Brookhart, 2004, p. 6). Therefore, in this part of the chapter, we use the word *evaluation* to indicate the general well-rooted structural feature of education systems aimed at making decisions on students' learning outcomes or paths. We use the word *assessment* to denote the kind of tool used by teachers to collect information about students' performance either on tests, homework, or classroom activities. Assessment is divided based on the reference used to compare the collected information. Criterion assessment refers to an assessment in which information is used to compare students' performance to a criterion decided a priori. Differently, normative assessment refers to an assessment in which information is used to compare different students' performances (Brookhart, 2004).

In this chapter, we focus on the grading evaluation system, the most common type of evaluation in OECD countries (OECD, 2013b). Grades (also called *marks*; OECD, 2013b) are value-laden symbols (e.g., a letter or a number) that summarise students' performance in a simple number and constitute an easily interpreted criterion of success or failure (Ames, 1992;

Knight & York, 2003). Due to their simplicity, grades can be easily used to compare different students' performances, and thus, they are a perfect means for normative assessment.

2.1. The detrimental effects of grading on learning and motivation

Grades are based on assigning a value to a performance task. This value reflects a hierarchy (e.g., the better the performance, the higher the value of evaluation), summarises students' performance in a simple number, and constitutes an easily interpreted criterion of success or failure. Through their simplicity and clarity, grades provide visibility to the students' achievement by highlighting differences among students. These differences induce a social comparison, which could threaten students' self-esteem and self-worth when they are not assured of their superiority (Butera et al., 2021; Muller & Butera, 2007).

Although norm-referenced grading is highly used in school (OECD, 2013b), it has been shown that it may have detrimental effects on students' learning process, motivation, and achievement. For instance, Ames (1992) suggested that the normative aspect of grading leads students to an ego-oriented focus on ability. This means that when students are evaluated with grades, they focus on demonstrating their ability compared with others instead of mastering the task. Demonstrating one's ability compared with others refers to the performance goal orientation described in the achievement goal theory (Elliot & Hulleman, 2017). According to this theory, performance goal is divided into performance-approach and performance-avoidance goals which are related to performance differently: The former has been originally linked with higher motivation and positive learning outcomes, and the latter with a decrease in students' motivation (e.g., Elliot & McGregor, 2001; Murayama & Elliot, 2012). It is worth noting that a clear link between performance goals (both approach and avoidance) and motivation and achievement has been questioned by some scholars who proposed, for instance, a multiple-goal perspective (e.g., Barron & Harackiewicz, 2001). However, recent studies demonstrated that grades enhance performance-avoidance goal

endorsement in students (Pulfrey et al., 2011) and reduce intrinsic motivation by decreasing students' perceived autonomy (Pulfrey et al., 2013).

A series of experimental studies demonstrated that grades hamper several learning-related activities, which are useful for increasing performance. For instance, it has been shown that grades elicit the preference effect in students (Hayek et al., 2014). The preference effect is the tendency to look for evidence that supports one own's point of view rather than seeking confrontation with an opposing point of view. This bias is very common in group situations (e.g., class situations), and it is elicited by standard methods of evaluation, especially when competition is made salient (Butera et al., 2018). When graded, students prefer to look for evidence in line with their points of view, hindering the improvement of their capabilities to consider alternatives, which is an essential ability that education should develop in students. Other studies demonstrated that grades decrease the amount of helpful information shared between students during a group problem-solving task (Hayek et al., 2015) and negatively affected the performance and intra-group relations of students while performing a cooperative game (Hayek et al., 2017). Furthermore, norm-referenced grades decrease school engagement throughout school years (Poorthuis et al., 2015) and undermine low-ability students' achievement (Klapp, 2015).

Furthermore, normative grading may hinder the possibility of perceiving errors as an opportunity to learn. Indeed, the grades obtained are linked with the quality of the performance, and if the value of the evaluation is below a specific aspiration level, the student may experience failure (Grassinger & Dresel, 2017). It is, therefore, possible to assume that evaluation may increase students' fear of failure, namely the "tendency to avoid mistakes because they may be regarded as shameful and could be a signal of lack of innate ability." (OECD, 2019, p. 188). As shown in Chapter 2, learning from errors depends on adaptive emotional and motivational students' reactions (i.e., affective-motivational reactions towards

errors). However, if linked to grades, errors may acquire a negative meaning. Students may focus only on their subsequent negative consequences (i.e., signs of inability and being judged by others), thereby increasing their error avoidance attitude, fear of failure and decrease their motivation.

3. Evaluation as a tool for reproducing social norms and cultural values

Education systems are social institutions that socialize students to the dominant ideologies in society (e.g., Apple, 2018). Elwood and Murphy (2015) argued that social and educational policies and structures constitute and replicate shared cultural values about educational achievement, success, failures, and what is legitimated and valued in society. These cultural values affect how the learner, the learning process, and teaching are defined, and these definitions pass through generations, becoming sedimented in expressions of practices. Accordingly, evaluation is not only a way of judging students' performance (e.g., Brookhart, 2004), but also an education system feature, which acts as a source of practices that reproduce certain cultural values and social norms (Elwood & Murphy, 2015).

An example of how evaluation systems echo cultural values and social norms is derived from the experimental studies of Autin and colleagues (2019). The authors showed how educational systems reproduce inequalities in society by favouring already privileged students through evaluation. In line with Darnon and colleagues (2009), the authors argued that the educational system serves two different functions: educational and selective. The educational function aims to provide all the students with education, knowledge, and skills that are fundamental for becoming an active part of society. The selective function aims to classify students based on their academic achievements and to select and divide them into different educational paths, and thus, different positions in society. In this respect, a norm-

referenced grading system is the perfect means to rank students according to their achievement outcomes and select more deserving students.

On the contrary, according to the authors (Autin et al., 2019), formative assessment, which is based on giving formative feedback and comments for assessing performance, fulfils the educative purpose of the educational system. The authors found that participants in their experiments (i.e., the evaluators) assessed a fictitious test performed by supposed students either with high or low SES (socioeconomic status) according to the function of the evaluation used. More precisely, when the evaluators used grades (i.e., normative assessment, linked to the selective purpose) to assess the fictitious test, they found more errors in the test of low-SES students than high-SES students. This difference decreased when evaluators used formative assessment (i.e., linked to the educative purpose) to evaluate the test.

In the same line, Butera and colleagues (2022) argued that normative assessment is the means through which the educational system replicates competitive values (e.g., meritocracy) and norms (e.g., productivism), broadly shared in neoliberalism societies. Indeed, as shown in the previous section, grading highlights differences between students based on their performance. This stress on the students' performance risks being overestimated, transforming errors into something to avoid since they point out a decrease in the performance, and thus, in the grade obtained. Therefore, it is possible to argue that competitive values and school accountability focus are associated with a detrimental meaning of making errors.

In this scenario, teachers may have a role in conveying a specific meaning of errors while teaching, as they act as social agents who socialise students to the broader cultural context (see Butera et al., 2021). In line with that, in the next section, we discuss how teachers' beliefs about assessment mirror the cultural values just described.

3.1. Teachers' beliefs about assessment mirror cultural values

As shown above, educational systems reproduce social norms and cultural values through their structural features (i.e., evaluation), which may affect both teachers' practices and beliefs. It is not surprising that, according to teachers, one of the evaluation purposes is school and students' accountability. More precisely, teachers believed that assigning grades allowed placing students into classes based on performance and separating them into different levels of education according to the results of selective examinations (e.g., Brown, 2004).

According to Brown (2008), teachers recognized other evaluation purposes related to four different teachers' beliefs. First, evaluation serves as a signal for learning and teaching improvement. Second, evaluation makes schools and teachers accountable. Third, evaluation makes students accountable for their learning, and fourth, evaluation is irrelevant for education and learning. The author argued that these beliefs could be expressed by the same teacher together, creating a sort of tension (Brown, 2004). In the same line, Barnes (2014) divided teachers' beliefs about assessment on a continuum with the extremes of, on the one side, the pedagogical purpose, and on the other side, the accounting purpose. The first refers to the use of evaluation for learning, which references the idea of the formative assessment (e.g., Black & William, 2010). The second refers to the belief in using evaluation to account for the effectiveness of school and the quality of students.

Teachers' beliefs about evaluation purposes reflect the two functions of educational systems described by Darnon and colleagues (2009). More precisely, the belief that evaluation is useful to account for schools, students, and teachers' effectiveness (Brown, 2008; Barnes, 2014) is in line with the selective function of educational systems (Darnon et al., 2009) and mirrors the increasing focus on school accountability, students' performance (Figlio & Leob, 2011), and competition (Butera et al., 2022). In line with that, Butera and colleagues (2021) pointed out that when teachers use normative grading to select students, they are fulfilling the

selective function of the education system and playing the gatekeeper role. Therefore, teachers internalize social ideologies shared in the society, such as competitive ideologies, and they transmit them to the students via several practices, among which normative assessment is one of the most common (Butera et al., 2022).

4. Conclusion

Including mistakes in the learning process and creating a supportive classroom environment (i.e., a positive error climate) are two necessary teachers' practices to promote an adequate use of errors and foster students' adaptive reactions. However, the pervasive use of normative assessment in compulsory education (OECD, 2013b), which mirrors the competitive values and the focus on school accountability, may make it difficult for teachers to include errors in the learning activities and handle them positively since errors should be taken into consideration while assessing students' performance.

Therefore, it is possible to argue that normative grading may contribute to hindering the possibility that teachers present errors as a steppingstone for students' learning. To date, only a few studies focused on teachers' beliefs about errors, and no research has studied how teachers perceive and reflect on the interdependence between errors and normative grading. Therefore, this cultural aspect of the role of errors in the learning process should be further investigated.

Chapter 5

Research questions and overview of the empirical studies

1. From psychological to socio-cultural mechanisms

As stated in Chapter 1, in this dissertation, we investigate the role of errors in the learning process by considering three levels of analysis: psychological, relational, and cultural (Mercer & Littleton, 2007). As for the psychological level, we described the learning from errors model (Tulis et al., 2016) that explains the self-regulated processes triggered after the error detection (Figure 2, Chapter 2). As for the relational level, we presented empirical findings on perceived error climate (Steuer et al., 2013), an environmental feature related to students' mistakes. Furthermore, expanding the theoretical model presented by Tulis and colleagues (2016), we analysed different studies focused on the role of teachers in creating an error-friendly environment (Chapter 3). Finally, in Chapter 4, we examined how shared ideologies and cultural values (e.g., competitive values) conveyed by education systems and connected to normative grading may alter the relevance of error in learning.

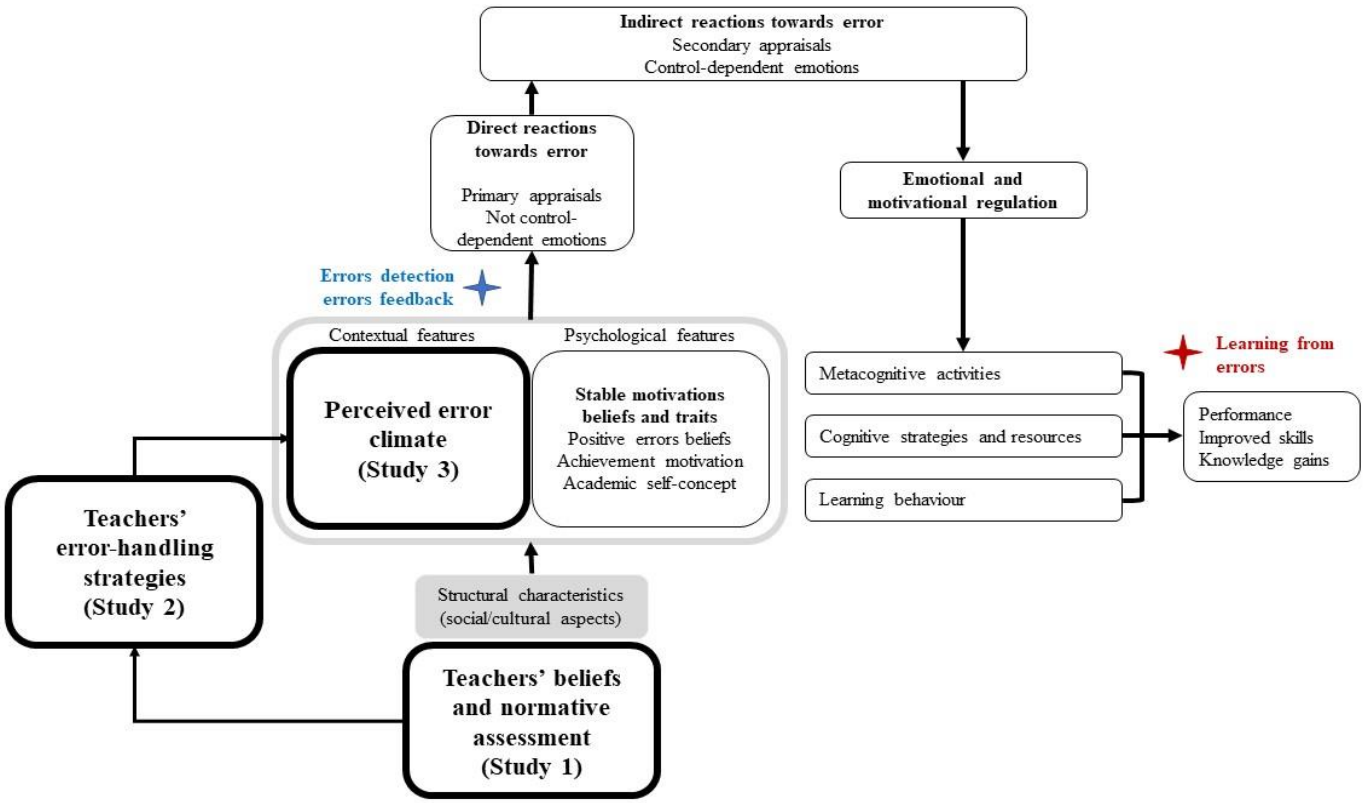
Based on the literature review presented in the theoretical section, the role of errors in the learning process varies depending on whether students can regulate their reactions to errors, how errors are framed in the classroom and handled by teachers, and the kind of cultural meanings with which errors are associated. Accordingly, the general aim of the empirical section is to study how cultural and relational variables affect the psychological mechanisms elicited by making mistakes. Therefore, by expanding the learning from error model (Tulis et al., 2016), we analyse the relationship between teachers' error-related beliefs and their error-handling practices, the contribution of these practices in promoting a positive error climate, and the role of the positive error climate in fostering students' adaptive reactions towards errors.

2. From literature gaps to research questions

The path outlined in the theoretical part (Chapters 1- 4) started from the psychological aspects related to the role of error in the learning process and ended with the description of the cultural facets. In the presentation of the empirical studies, we will follow the opposite path (Figure 3). We describe the different cultural meanings errors acquire in the learning context (cultural level), then the teachers' practices that promote a positive error climate (relational level), and, finally, we show how the error climate influences students' reactions towards errors and foster better school results (psychological level). This order was chosen to make a clearer link between levels and to show how broader aspects (i.e., cultural facets) may influence narrower mechanisms (i.e., psychological dynamics).

Figure 3

The Learning From Errors Model Adapted from Tulis and Colleagues (2016, p.19) and Relational and Cultural Aspects Studied in the Empirical Part of this Dissertation



2.1. Cultural level

In Chapter 4, we considered teachers as agents of socialisation (Butera et al., 2021) who, through their practices, may convey social norms and cultural values related to errors by implementing the normative assessment. Teachers' practices may be informed by teachers' beliefs related to errors. Previous research on teachers' beliefs about errors and their link with teachers' practices provided inconsistent results (e.g., Bray, 2011; Empson & Junke, 2004; Schleppenbach et al., 2007). Furthermore, to the best of our knowledge, no research has investigated teachers' beliefs about the relationship between errors and evaluation.

Accordingly, the first empirical study addressed the following research questions:

- What are teachers' beliefs about errors in the learning process?
- How do teachers describe their error-handling practices usually used during learning activities?
- How do teachers reflect on and manage the relationship between students' errors and grades?

To answer these questions, we carried out an exploratory qualitative study to investigate teachers' beliefs about errors and the relationship between errors and evaluation, as well as their link with teachers' practices.

2.2. Relational level

As shown in Chapter 3, only a few studies explored how teachers' error-handling strategies contribute to creating an error-friendly environment (e.g., Rach et al., 2013) using an experimental approach. Furthermore, none of the empirical or observational studies presented (Chapter 3, section 2) has measured the perception of a positive error climate through Steuer and colleagues' (2013) instrument.

Accordingly, the second study's main research question was:

- How could different error-related teaching strategies lead to a difference in pupils' perceived error climate?

We implemented a quasi-experimental study with a pre-test/post-test design focused on teachers' error-handling strategies. We manipulated teachers' error-handling strategies using a script based on Tulis's results (2013). The manipulation consisted of dealing with primary school pupils' errors either positively or neutrally during a fictitious lesson. The researcher handled students' errors by adopting different strategies for the positive condition (e.g., emphasising the error learning potential; discussing with the whole class) and for the neutral condition (e.g., ignoring the errors). We measured the perceptions of perceived error climate before and after the manipulation, administering a short version of the perceived error climate questionnaire (Steuer et al., 2013) for the first time in Italian primary classrooms.

2.3. Between relational and psychological levels

The last study focused on the relationship between relational and psychological levels. Indeed, in Study 3 we analysed the association between perceived error climate and adaptive reactions towards errors. Although some research has already shown that perceived error climate fosters adaptive reactions towards errors (e.g., Steuer et al., 2013) and learning outcomes (e.g., Grassinger et al., 2018), these effects need to be further investigated. In addition, to date, no research has tested a comprehensive model in which different error-related variables (i.e., perceived error climate, adaptive reactions towards errors, error beliefs) are considered together.

Therefore, the research questions of the third study were:

- Is a perceived positive error climate associated with students' learning outcomes in mathematics via adaptive reactions towards errors?
- Is this association based on a serial mediation effect in which affective-motivational reactions act as the first mediator and action reactions as the second mediator?

Using a multilevel model, we tested the serial mediation model linking perceived error climate with learning outcomes via the two adaptive reactions towards errors. As a measure of students' learning outcomes, we collected mathematics grades obtained by the students at the end of the first term of the school year (January 2020). We controlled for other variables related to the learning from errors model. We provided, therefore, the first results on a comprehensive model in which several psychological and environmental variables interact together.

3. Overview of the empirical studies

The three empirical studies have been conceived as three independent research, with their theoretical background, methodology and discussion. Each study focused on different samples and was carried out during different school subjects' classes (Study two, Civic education lesson, and Study three, mathematics lesson). An overview of the features of the studies is presented in Table 1.

Table 1
Characteristics of the Empirical Studies. Approach, Aims, Sample, and Methodologies are Described

Chapter	Level of analysis	Approach	Main aims	Sample	Methodology
6	Cultural	Qualitative	To investigate teachers' beliefs about students' mistakes and their link with teachers' practices. To explore whether teachers reflect on the interdependence between the evaluation system (i.e., normative grading) and students' errors.	Primary, middle and secondary school Italian teachers (N = 33)	Interviews
7	Relational	Quantitative (experimental)	To test whether different error handling strategies (supportive vs neutral), could lead to a difference in pupils' perceived error climate.	Primary school pupils (N = 108)	Pre-test/post-test design and experimental manipulation
8	Relational-Psychological	Quantitative (correlational)	To test a serial mediation process where the perceived error climate is indirectly associated with students' learning outcomes via adaptive reactions towards errors	Middle school students (N = 561)	Cross-sectional survey

Chapter 6

Errors: Springboard for learning or tool for evaluation? Ambivalence in teachers' error-related beliefs and practices[3]

Abstract

Teachers can effectively promote an error-friendly learning environment by implementing supportive practices to deal with students' mistakes. Teachers' error-related practices may be linked to their beliefs about errors and other features of the learning environment, such as the evaluation system. However, little is known about teachers' error-related beliefs and practices and their interplay with evaluation practices. Accordingly, this study's aim was twofold: (a) to investigate teachers' beliefs about the role of errors in the learning process and their relationship with error-related practices, and (b) to explore whether grading influences teachers' reflections on their error-related beliefs and practices. To do so, thirty-three Italian primary, middle and secondary school teachers were interviewed. Participants were asked to reply to semi-structured interviews. The qualitative data were analysed through reflexive thematic analysis. The seven themes identified suggested that teachers believed that errors acquire different meanings (i.e., pedagogical, sanctioning and threatening) that are related to their roles in learning. Furthermore, these beliefs were closely related to teachers' error handling practices adopted during learning activities. Finally, teachers clearly acknowledged that grading hampers the possibility of handling students' errors supportively because errors generally result in lower grades. Our results reveal the ambivalence of teachers' beliefs and practices about errors and shed light on teachers' difficulties in framing errors positively while assessing students with grades.

Keywords: Teachers' beliefs, Teachers''practices, Errors, Grading, Interview

[3] Paper in preparation.

Introduction

Errors are an integral part of learning, and they may have an essential role in boosting achievement (e.g., Metcalfe, 2017; Kapur, 2014). Nevertheless, making errors at school may lead to negative consequences for students, such as being mocked by classmates, scolded by the teacher, or receiving a bad grade. In particular, grades, a widely used evaluation system (OECD, 2013), are negatively related to errors: the higher the number of mistakes in a test, the lower the grade. Therefore, errors may easily become a marker of failure rather than an opportunity to learn, increasing students' fear of making mistakes and negative emotions (OECD, 2018).

Given that errors may be a double-edged sword, the role of teachers is crucial. Teachers, indeed, may contribute to creating an error-friendly classroom environment by adopting supportive error handling practices (e.g., Soncini et al., 2020). Teachers' practices are influenced by their beliefs and learning environment characteristics, such as the organization of classroom activities (e.g., Santagata, 2004). Although a great deal of research explored how teachers' error handling practices influence the classroom environment (e.g., Heinze & Reiss, 2013; Tulis, 2013), only a few studies investigated teachers' beliefs about students' errors and their relationship with error-handling practices (e.g., Bray, 2011; Schleppenbach et al., 2007). Furthermore, little is known about how the characteristics of the learning environment, in particular grades, may affect how teachers deal with students' errors.

Therefore, the aim of this research was twofold. First, to explore teachers' beliefs about errors' role in the learning process and their link with practices aimed at handling these errors. Second, to understand whether evaluation based on grades influences how teachers reflect on errors and deal with them. To address these research questions, we carried out an exploratory qualitative study based on the analysis of thirty-three interviews carried out with Italian primary, middle and secondary school teachers.

Teachers' Beliefs and Practices Related to Students' Errors

Several scholars have sought a consensual definition of teachers' beliefs to clarify how these psychological structures influence teaching practices, but to no avail (e.g., Fives & Buehl, 2012). The lack of a univocal definition of teachers' beliefs mirrors the lack of agreement in the literature about their relationship with teachers' practices. Evidence shows that both beliefs influence practices and practices influence beliefs (Buehl & Beck, 2015) and that teachers' beliefs and practices reciprocally influence one another (e.g., Basturkmen, 2012; Richardson, 1996; Thompson, 1992).

Likewise, studies focused on teachers' error-related beliefs and practices provided inconsistent results (e.g., Bray, 2011; Empson & Junk, 2004; Santagata, 2004; Schleppenbach et al., 2007). For instance, Schleppenbach and colleagues (2007) found that teachers considered errors as natural aspects of the learning process that help students understand their limits and as events not always helpful in developing knowledge. In a case study with four participants, Bray (2011) corroborated Schleppenbach and colleagues' (2004) results, showing that different teachers' beliefs influenced how teachers structured the lesson. Indeed, teachers who believed that errors provide learning opportunities focused the classroom discussion on students' errors. However, Empson and Junk (2004) pointed out that teachers who believed errors are an important learning opportunity did not report adopting error-handling practices consistent with this belief.

In addition, Santagata (2004) found that U.S. and Italian mathematics teachers deal with students' errors differently according to, on the one hand, different teachers' beliefs (which Santagata called *cultural beliefs)* and, on the other hand, the characteristics of the lesson. More precisely, the author found that Italian teachers discussed students' errors publicly more often than U.S. teachers. This difference was interpreted by comparing Italian and U.S. teachers' beliefs about students (i.e., students should be pushed to do exercises and students' self-esteem should be reinforced and protected, respectively), and analysing the

differences in mathematic lessons. For instance, in Italy, exercises are often solved on the blackboard in front of classmates, whereas in the U.S., students mostly solve the exercises alone.

Overall, a complex and not linear relationship between teachers' beliefs, practices and structural classroom characteristics emerged from the literature mentioned above. Accordingly, the first aim of this study was to explore teachers' beliefs about the roles of errors and whether these beliefs are linked with teachers' error-related practices.

The Effects of Grading on Teachers' Error-Related Practices

In line with Santagata's (2004) results on the influence of the learning environment on teachers' error-handling practices, in this paper, we focused on grading. Grading is a widely implemented assessment tool (OECD, 2013) based on applying a simple value-laden symbol (e.g., a letter or a number) to summarise academic performance value. Due to their simplicity, grades allow to easily rank students according to the value of their performance (i.e., the obtained grade, Pulfrey et al., 2011), thereby increasing the *normative* aspect of assessment (i.e., comparing the performance of a classroom's students, Brookhart, 2004).

A wealth of research showed that normative grades have detrimental consequences on students' learning and motivation (Ames, 1992; Hayek et al., 2014; 2015; Klapp, 2015; Poorthuis et al., 2015; Pulfrey et al., 2011; 2013), consequences due to the competitive social comparison that grades elicit, which may threaten students' self-esteem (Butera et al., 2006; 2021). Despite this, most OECD countries' education systems are based on grades (OECD, 2013). In the Italian education system, grades are typically used to assess several learning activities, such as homework or teaching unit tests.

When using grading, teachers must take errors into account to assess the value of the performance. In this respect, errors and grades are characterized by a negative interdependence: The higher the number of errors in a performance test, the lower the

likelihood of obtaining a good grade (Weingart, 2004). Therefore, this negative interdependence may transform errors from being steppingstones for learning into a tool for assessment. If teachers must evaluate students' performance through grades, it could be possible that promoting a positive approach to errors may be challenging for them. Accordingly, the second aim of this study was to explore how teachers reflect on the way normative grading affects their error-related practices.

The Present Study

The above results reveal an intricate interplay between teachers' beliefs and their error-related practices. Furthermore, the relationship between teachers' error-related beliefs, practices, and the use of grades has not been explored yet.

The present research was designed to fill in these gaps, and its aims are twofold. First, to explore teachers' beliefs about the role of errors in the learning process and the links between these beliefs and their practices in handling errors. Second, to explore how teachers reflect on the link between the use of grading evaluation, a pervasive feature of the learning environment, and the practices they implement in their classroom to deal with students' mistakes. We conducted an exploratory qualitative study based on semi-structured interviews with Italian teachers.

Method

Procedure and Participants

The present study was the qualitative part of a large mixed-method research project involving Italian teachers, which comprised a quantitative online survey and semi-structured interviews. At the end of the survey, teachers interested in participating in the interview communicated their e-mail addresses (n = 150 over 1100 teachers who replied to the survey), and thus, were informed about the interview's content and were asked to sign the consent form. Participants were selected according to the school level in which they taught (i.e.,

primary, middle, or secondary school) and their region (i.e., northern, central, or southern region) to have a balanced sample. Therefore, we selected ten participants for each school level among these teachers, balancing the regions. In the first wave of invitation e-mails, we contacted 30 teachers (15 from the north, 9 from the centre, and 6 from the south) and only 8 teachers agreed to be interviewed. Thus, we contacted other teachers and implemented the same sampling procedure for four weeks.

The final sample comprised 33 Italian teachers (M_{age} = 51.69, *SD* = 7.35, 27 women), divided into the three school levels: primary (*n* = 10), middle (*n* = 10) and secondary school (*n* = 13). The overall sample comprised teachers with 1-35 years of experience (*M* = 23.30, *SD* = 8.49). Specific characteristics of the three groups of teachers are presented in Table 1.

Table 1
Descriptive Characteristics of the Participants of the Three Groups in Which they are Divided According to the School Grade

Sample group	N	Age Mean (S.D.)	Gender	Regions [a]	Years of teaching Range/ Mean (S.D.)	Subjects taught
Primary school teachers	10	49.50 (25.11)	9 women 1 man	7 Northern Italy 2 Central Italy 1 Southern Italy	14-34 20.81 (5.73)	6 Italian and history 1 mathematics and sciences 3 other subjects[b]
Middle school teachers	10	53.21 (6.17)	9 women 1 man	6 Northern Italy 3 Central Italy 1 Southern Italy	16-37 26.71(6.94)	4 Italian 2 mathematics 3 French and English as L2 1 music
Secondary school teachers	13	52.23 (8.63)	9 women 4 men	9 Northern Italy 2 Central Italy 2 Southern Italy	1-35 22.61 (10.77)	4 mathematics 5 Italian and philosophy 2 laws 2 English as L2

Note. The total of the sample is 33 teachers divided into three groups, based on the Italian education system division
[a] The regions are Emilia-Romagna (Northern region), Marche (Central region), and Sardegna (Southern region).
[b] In the Italian primary school, teachers have different roles determined by school regulations. In some schools, two teachers teach the main subjects in the same classroom (i.e., one teacher for STEM subjects and the other one for literature/humanities subjects). In other schools, one teacher (called main teacher) teaches all the main subjects in each classroom, supported by another teacher (called support teachers) who teaches other subjects, such as music or physical education. In our primary school sample, 7 teachers were main teachers of the classroom, whereas three teachers were support teachers.

The Italian Education System

The Italian education system is divided into primary school (for pupils aged between 6 and 11), middle school (for pupils aged 11 to 13), and secondary school (for students aged 14 to 19). Each school level is characterised by specific features regarding the schedule, the subject taught, and the daily activities' organisation. Nevertheless, the three levels share the same evaluation system based on grades. Grades are required by the Law (Law 168/2008) and are used by teachers to account for students' progress throughout the school year.

During classroom learning activities, teachers usually test students' learning levels at the end of each teaching unit. The average of all these evaluations, collected by the teacher and expressed in grades, constitute the two summative evaluations of the year. In the middle (mid-January) and at the end (mid-June) of the school year, students receive a formal school report, which qualifies students' achievements. The summative assessment at the end of the school year is also used to decide whether the student passes the school grade.

Even though a formative approach to the evaluation is recommended by the Italian Ministry of Education guidelines, grades are mandatory and are usually communicated to the students after every assessment. Students are, therefore, used to receiving grades almost daily for different tasks and performance tests

Interview and Data Analysis

The data collection took place between June and July 2020, and the interviews were carried out online, audio-recoded, and transcribed verbatim by three researchers separately. The interviews lasted between 30 and 100 minutes (M = 49.82, SD = 17.28). A semi-structured exploratory interview schedule was created based on three research questions related to the main aims of the study (Table 2). The first draft of the interview schedule was discussed by the three researchers who carried out the interviews and then revised by another researcher not involved in the data collection.

Table 2
Research Questions and Interview Schedule

Research questions	Interview schedule
/	Personal and professional information
1. What are teachers' beliefs about errors in the learning process?	What is the role of students' errors in the learning process? Do you think that your students are afraid of making mistakes?
2. How do teachers describe the way they usually handle students' mistakes during learning activities?	When one of your students makes a mistake in the classroom, how do you usually react to this situation?
3. How do teachers reflect on the relation between students' errors and grading practices?	What is the relationship between students' errors and evaluation in your teaching practice? How do you handle that?

Transcriptions of the interviews were analysed through a reflexive thematic analysis (Braun & Clarke, 2012), characterised by flexible identifications of patterns into a dataset (Braun & Clarke, 2006). We did not use any coding schema a priori and the analysis is a interpretative reflexive process (Braun & Clarke, 2020). We employed a deductive approach to the data, which means that theoretical frameworks are the lens through which data are analysed and interpreted (Braun & Clarke, 2006).

We followed a specific procedure to create the themes. First, we divided interviews according to school level among the three researchers, who familiarised themselves with a corpus of interviews related to a single school level. Second, each researcher coded the interviews, considering codes as an analytic unit that refers to one facet (Braun & Clarke, 2020). Third, initial themes were created by gathering codes that shared similar meanings (see Table 2 for the final coding scheme). Themes are multi-faceted and complex topics (Braun & Clarke, 2020) with a higher degree of generality (Vaismoradi et al., 2016). Finally, the three researchers discussed the initial themes together, reviewing them according to the codes that emerged in the coding analysis, the research questions, and the literature.

Results

A total of seven themes emerged from the data. We present the themes by dividing them into two main levels that reflect the two main areas explored through the interview: *Teachers' beliefs* and *Teachers' practices*. We used the word *practices* to indicate practices reported by teachers and not observed since we only accessed information provided by the participants during the interviews. The levels, themes and codes are presented in Table 3.

Teachers' Beliefs Level

This level reflects the research interest in exploring what teachers believe about their students' errors and the relationship between errors and evaluation. It comprises four themes that provide an overview of the complex and ambivalent teachers' beliefs on these topics.

Theme 1: Mixed teachers' attitudes towards errors. This first theme describes teachers' attitudes towards errors in the learning process. We defined these attitudes *mixed* because teachers expressed both positive and negative attitudes. More precisely, most of the participants (n = 24, code 1) clearly expressed positive attitudes towards errors: they were described as "*fundamental*" and essential for learning.

However, some teachers (n = 9, code 2) stated that if errors are reiterated, they may hamper learning. The repetition of the same error is defined as a "*loss in the learning process"* and the cause of this repetition is the lack of students' commitment and study.

"The error has a positive value, not negative, that is for sure. It becomes negative if it is repeated and done because you did not want to study. But if it is positive, it is the starting point to recover and to look at what you can do better… then it is ok." (primary school, 53 years, female).

As shown in the quote above, the same teacher expressed both positive and negative attitudes towards errors, making clear that errors are different: there are errors due to a lack of study, which may hinder learning, and errors due to a lack of understanding, which support learning. This hampering shade highlighted by some teachers is mirrored in the following themes as well, although in different ways.

Table 3

Levels, themes, respective codes and total number of teachers who reported each specific code and division into the three school levels

Levels	Themes	Codes	Total number of teachers (N = 33)	Primary school teachers (N = 10)	Middle school teachers (N = 10)	Secondary school teachers (N = 13)
Teachers' beliefs level	1. Mixed teachers' attitudes towards errors	1. Errors fundamental for learning (positive attitudes)	24	8	7	9
		2. Errors are negative if reiterated (negative attitude)	9	4	4	1
	2. Different roles of errors in the learning process	3. Errors as a source for learning and reflection	21	9	4	10
		4. Errors highlight that every student has limits (educative role)	6	/	2	4
		5. Errors help teachers to modulate instruction and teaching practices	13	5	3	3
		6. Error helps students who want to learn from them	16	3	7	7
	3. Causes of students' fear of making errors	7. Errors are frustrating	8	4	1	3
		8. Fear of disappointing the teacher	4	2	1	1
		9. Fear of disappointing parents	5	3	1	1
		10. Fear of being judged by others	10	3	2	5
		11. Students' personal features (i.e., shyness)	16	4	5	7
		12. Past experiences	6	2	1	3
	4. Unbalanced negative interdependence between errors and evaluation	13. Negative relationship between errors and grades	15	7	1	7
		13a. Errors must be evaluated	10	2	3	5
		13b. Errors became the projection of a bad grade	5	1	2	2
		14. Errors and evaluation relationship not balanced	7	4	1	2
Teachers' practices level	5. Negative and positive teachers' error-handling strategies	15.Negative reactions only for students lack study/commitment	13	4	5	4
		16.Encouraging, supporting students in finding a solution	26	9	7	10
		17.Class correction of the error (class discussion)	12	6	4	2
		18.Reaction changes according to the situation	6	2	2	2
	6. Making students errors experience positive	19.Avoiding stigmatization	11	4	4	3
		20.Reassuring pupils/Creating a positive climate	15	5	2	8
		21.Contextualising and framing pupils' mistakes	4	2	2	/
		22.Using Irony	7	1	3	3
	7. Dealing with negative interdependence between errors and evaluation	23.Sharing evaluative criteria with pupils	10	6	2	2
		24.Explaining the grade and giving it a meaning	18	8	6	4
		25.Giving the tasks without a mark, or after the correction	8	2	4	2
		26.Emphasising more learning and errors than test and evaluation	5	2	3	/

Theme 2: Different roles of errors in the learning process. This theme represents teachers' beliefs on the different roles the errors might play in the learning process. In line with the previous theme, most of the participants (n = 20, code 3) stated that errors act as a source for improving learning. Furthermore, some of the teachers (n = 13, code 5) recognised errors have a useful role also for themselves, as a signal that something in the teaching practices and instruction should be changed.

"*An error is useful because it lets me see where my explanation of the topic was not clear enough and where I couldn't reach the pupils who made a mistake*" (primary school, 57 years, female).

A few middle and secondary school teachers (n = 6, code 4) highlighted that students' errors might act as an educational tool to help students understand and accept their limits. According to these teachers not all the students are able to deal with their errors in an efficient way.

"*The role of errors is to get students used to being humble because now all the students think to be "born-learned" (*from the Italian way of saying, "nato imparato", a hyperbole meaning that they already know everything at birth, ed.*), and it is not good at all. Focusing on mistakes leads you to accept your limits*" (secondary school, 54 years, female).

Furthermore, several teachers (n = 16, code 6) recognised that errors effectively support learning only if students understand them and are interested in working on them. This belief revealed the idea that students are responsible for their learning and the teacher is only a guide that "*leads students to work on their errors*".

"*[the possibility to learn from errors, ed.] a lot depends on the willingness: if the student doesn't care, then he/she doesn't tell you and the next time in the test he/she gets the same thing wrong. Those students who take a serious course, on the other hand, will eventually ask you to work on it, and so in most cases, it will work."* (middle school, 53 years, female).

As in the previous themes, teachers expressed ambivalent beliefs about the role of errors. Errors are considered helpful for learning when students are engaged in their learning

process, whereas if students do not stive to succeed errors become useless, like a barrier to learn.

Theme 3: Causes of students' threatening errors perceptions. In this theme teachers put themselves in the students' shoes to explain why they might be afraid of making errors. Some participants (n = 8, code 7) clearly stated that making errors is frustrating for their students, whereas other teachers stated that indirectly, by explaining why their students might perceive their errors as frustrating.

"It is difficult to make the students understand the positiveness of making errors, because for them an error is a "stab in the back", it means "oh God I am inadequate"." (secondary school, 63 years, female).

Most of the teachers (n = 16, code 11) reported that students are afraid because of their internal features, such as shyness, passivity, insecurity, or disinterest. Other possible explanations refer to external causes. More precisely, some teachers reported the fear of being judged by the others (i.e., classmates; n = 10, code 10), of disappointing the teacher (n = 4, code 8) and parents (n = 5, code 9) as possible reasons why students are afraid of making errors. Finally, the past experiences in terms of parents' expectations and past teachers' behaviour were also listed as possible external causes (n = 6, code 12).

"*If a student raises his/her hand and makes a mistake there is the judgement of the whole class... it is very important at that age, it is decisive... a kid who is looked at badly by others... his self-esteem goes down..."* (middle school, 60 years, female).

In this theme, errors are described as something threatening and frustrating for the students, and teachers also expressed their beliefs about possible causes of that. It is important to note that teachers reported causes related to external or internal features of the students (i.e., classmates' judgments) without however considering their own teaching practices.

Theme 4: Unbalanced negative interdependence between errors and grades. This last theme of the Teachers' beliefs level revealed how teachers reflect on the relationship between students' errors and grades. Several teachers (n = 15, code 13) recognised that errors

are linked with negative evaluations and bad grades. Delving into this code, it emerged that according to some of those teachers (n = 10, sub-code 13a), grades are a deeply rooted feature of the school system, and their role includes grading students' tests. For instance, teachers said that errors must be considered when grading because "*Grades must be used at school*" and "*Errors have a weight in an objective test.".* On the other hand, some other teachers (n = 5, sub-code 13b) expressed their difficulties in accepting this negative interdependence and dealing with it.

"Errors in our system of grids, objectivity, with parents assessing you, controlling you, is very brutal. One error is equal to one point less in the evaluation. I say that clearly. This is because the school system requires it. [...] For instance, the student who proved me that he/she has made progress, but he/she has also made mistakes, I can't emphasize his/her work (giving a good grade, ed)*. The system does not allow me to do so."* (secondary school, 54 years, female).

What is interesting and unexpected is that some teachers (n = 7, code 14) highlighted that the negative interdependence between errors and grades is not balanced. According to them, most of their students are more interested in knowing their grades than understanding the errors, and thus, errors may lose their role in fostering learning.

"Even though at middle school students are told "You learn by making mistakes", teachers grade the students' test, and they only focus on that. It works like that." (middle school, 49 years, female).

In this theme, a discrepancy between different beliefs on the approach to the evaluation-grades interdependence emerged. Some participants reported the mismatch between stressing the positive role of errors while negatively counting errors in the assessment of the performance tasks, whereas others expressed the necessity to use evaluation in their practices. As we will see in the last theme of the *Teachers' practices level*, teachers found their own strategies to frame errors positively despite the large use of grades.

Teachers' Practices Level

This level refers to the set of reported behaviours, affective reactions and teaching strategies teachers said to adopt when an error occurs during a lesson, and it is divided into three themes. These themes are closely related to those of the previous level, and they enrich the understanding of teachers' beliefs by adding information about their practices related to errors.

Theme 5: Supportive and discouraging error handling strategies. This theme comprises all the strategies teachers said they usually implement when students make mistakes during daily class activities. The teachers of our sample reported using several supportive error handling strategies to help students understand and overcome the errors. Most of the teachers (n = 26, code 16) reported that they support the student who made the error in understanding it and finding a solution. Primary school teachers often reported using a strategy like "*going hunting for errors*" while correcting written exercises and oral tests.

"*Depending on the age, it is good to point the error out, not correct it. While correcting text, I put a dot next to the sentence if there is an error. Then I say to the student: "Look for the error". If the student finds the error, we correct it.*" (primary school, 47 years, female).

Differently, middle and secondary school teachers stated that they support students in rethinking the error with a step-by-step procedure to revise the mental procedure implemented to give the answer. Furthermore, several teachers (n = 12, code 17) reported involving the classmates to start a class discussion to correct the error together.

Other teachers (n = 6, code 18) stated that they react differently according to the kind of errors, and some other participants (n = 13, code 15) reported that when they understand that errors are due to a lack of effort, their reactions change, becoming harsher, and they get angry with the student. They described this reaction as spontaneous and, to some extent, necessary.

"*If students had to study and they don't know the verbs because they didn't study, then, in that case, I get angry*." (middle school, 51 years, female).

Mirroring the attitudes (Theme 1) and the role of errors (Theme 2) reported by the teachers in the previous level, in this theme, teachers reported adopting different error handling strategies to deal with students' errors. Again, the main distinction is based on the kind of errors that occurred (i.e., errors due to a lack of understanding or to a lack of commitment).

Theme 6: Strategies to mitigate students' threatening perception of errors. This theme refers to several strategies that teachers said they use to make students perceive their mistakes positively. It is linked with the idea that students perceive their errors as frustrating (See Theme 3).

Most of the teachers (n = 15, code 20) reported that they tried to create a positive classroom climate in which students are not judged if they err. For instance, teachers discouraged classmates' negative reactions after an error, reassured students and pupils to prevent them from being demotivated and

"First of all, I create as positive an atmosphere as possible. […]. I just listen to the students, and I tend to let them express themselves, to let them make mistakes. Then, in a way that I think is appropriate depending on the student's personality, I start to point out what didn't work." (secondary school, 66 years, male).

Linked to this strategy, teachers (n = 4, code 21) reported that they tried as much as possible to "*frame the error as a useful signal*", and to avoid errors stigmatisation and personalisation by correcting the error in a respectful and calm way (n = 11, code 19).

"Even when correcting writings test, for example, I take sentences from their essays - without saying who made that error - and then work on them on the blackboard asking: 'What do we need to do to improve this?'." (secondary school, 64 years, female).

Finally, some teachers (n = 7, code 22) said to use irony to decrease the frustrating meaning errors might bring.

"*I am very ironic. I use irony because I know making mistakes is frustrating."* (middle school, 57 years, female).

Since teachers believed that students might be afraid of making mistakes, they reported using practices to decrease students' negative feelings. It is clear here how teachers' beliefs and reported practices are tied together, and this pattern is present in the next theme as well.

Theme 7: Dealing with negative interdependence between errors and evaluation. As shown in Theme 4, teachers recognised the negative unbalanced interdependence between errors and grades. Teachers said they adopt several strategies to mitigate the negative effect of grading on the potentially positive role of errors.

Most of the teachers (n = 18, code 23) deal with this interdependence by explaining both grades and errors carefully to the students and by sharing evaluative criteria before the test (n = 10, code 24). In this way, the positive role of errors in supporting learning by highlighting what should be improved may still emerge.

"*But the main thing is to explain these errors. The negative grade must serve as a signal to improve the next time. You always have to show the positive side. Then kids also need to see what they do wrong and have a picture of a moment that is useful to understand what they have to do."* (middle school, 51 years, female).

To solve the unbalance of the interdependence, some teachers (n = 8, code 25) said they decided to separate the handing out of the test and its evaluation or to emphasise errors more than the grade (n = 5, code 26). These strategies are used to prevent students from focusing on their grades only.

"*For a couple of years now, we have decided that the students don't see the grade on the test, because it triggers anxiety and competition [...] and they completely lose focus, which is the mistake… they just look at the grade*." (middle school, 49 years, female).

In this last theme, teachers' activities and strategies to deal with the negative interdependence between errors and grades emerged. Since teachers must evaluate their students through grades, they found their own teaching practices to support students in considering and using errors as a steppingstone for learning.

Discussion

The study aimed to explore teachers' beliefs about errors and their link with error-related practices and understand whether and how teachers reflect on the influence of grading on these practices. A total of thirty-three Italian teachers' interviews were analysed through reflexive thematic analysis, and seven themes emerged from the data. Here, we discuss the three main contributions of this paper, examining the extent to which they inform our research questions and the literature we have reviewed.

Different Meanings of Errors in the Learning Process

Overall, our findings showed that teachers believed that errors have different characteristics and play different roles in the learning process. When teachers expressed their general beliefs about errors and their roles, errors carried a *pedagogical meaning*. Errors are defined as essential for learning because they have a pivotal role in improving learning and instruction (Themes 1 and 2). In line with this, teachers reported supporting and encouraging students to learn from their errors (theme 5). This result is in line with other findings, which pointed out that teachers who hold positive beliefs about the role of errors in school use them to structure their lessons (e.g., Bray, 2011).

On the contrary, errors acquire a *sanctioning meaning* when, according to teachers, they are due to a lack of students' commitment. In this case, errors are considered detrimental to learning (Theme 1 and 2), and the teacher should scold the student and penalise that error (Theme 5). Furthermore, errors should also be penalised when they could be used to guide students to accepting their limits or being humble (Theme 5). Both cases pointed out that teachers viewed students as responsible for these errors. This result mirrors Santagata's (2004) findings, which showed that Italian teachers hold beliefs (i.e., cultural beliefs) that students should be forced to do homework and are responsible for their own learning. Therefore, if they do not strive to succeed, teachers are justified in considering their errors

reprehensible. This explanation is in line with the attributional process described by Matteucci and Gosling (2004). When teachers attribute failure (making mistakes) to students' lack of effort (i.e., personal internal responsibility), the consequent emotional reaction is negative (i.e., anger), which leads to punitive behaviours. This external defensive attribution of teachers allows them to deflect responsibility for students' failure from themselves to the students.

Finally, when teachers put themselves in the students' shoes, they reported that students might be afraid of making errors because errors are viewed as threatening cues that increase frustration and negative emotions (Theme 3). In this case, errors acquired a *threatening meaning.* This threat may be exacerbated by the negative interdependence between errors and evaluation, of which teachers were aware (Theme 4). Teachers provided several explanations about why errors may become threatening for students by listing internal (i.e., the student's personal features) and external (i.e., social pressure, parents' expectations, and evaluation, of course, evaluative pressure) causes. It is interesting to note that, among external factors, teachers reported factors that do not include their own practices. This result is in line with Matteucci's (2007) findings, according to which teachers do not ascribe to themselves students' failure. One possible explanation could be that it is common to use more external than internal explanations for negative events (i.e., self-serving attributional biases; Mezulis et al., 2004). Considering making mistakes as something that should be avoided, or, at least, that may increase students' fear of errors, teachers may prefer to give external explanations to preserve their own self-esteem and self-concept.

Therefore, the first contribution of this study is to provide a rich depiction of teachers' beliefs about errors. In line with the literature (e.g., Fives & Buehl, 2011), our findings showed that teachers hold multifaced and complex beliefs about errors. The present research

specifies that errors acquire different meanings according to the roles teachers attribute to them.

Teachers' Error-Related Beliefs Underpin Their Reported Practices

Another contribution of our study concerns the relationship between teachers' error-related beliefs and their reported practices. Even though we did not observe their actual practices, we asked teachers to report how they usually deal with students' errors. During the interviews, therefore, teachers described various real-life scenarios in which the link between their error-related beliefs and their practices was made apparent. For instance, the *pedagogical meaning* of errors was in line with teachers' strategies aimed at including errors in the learning activities (Theme 5). Accordingly, teachers reported adopting several positive error handling strategies already described in the literature (Tulis, 2013). On the contrary, when the *sanctioning meaning* of errors emerged, teachers reported using practices to penalise mistakes, which have been considered maladaptive in previous literature (see Tulis, 2013).

Furthermore, when teachers recognized the *threatening meaning* of errors (considering the students' point of view), they reported implementing strategies to decrease students' frustration and fear of making errors (Theme 6). In the same line, when the threatening meaning of errors is exacerbated by using grading evaluation (Theme 4), teachers reported implementing specific strategies to stress the *pedagogical meaning* of mistakes (Theme 7).

Although our results cannot establish a causal link between beliefs and practices, one possible interpretation of these results is that beliefs about errors help teachers interpret errors and the circumstances in which they occurred. This interpretation may lead them to implement specific error-related practices. This result reflects the idea that teachers' beliefs act as a filter for interpreting information and experiences, frame situations and problems and guide intentions and actions (see, Fives & Buhel, 2011).

Normative Grading May Hamper the Possibility to Frame Errors Positively

Our findings revealed that teachers of the sample were aware of the negative interdependence between grades and errors. Furthermore, some teachers acknowledged that this negative interdependence is not balanced: students were described as far more interested in their grades than in understanding their errors (Theme 4). It is possible to identify two main approaches teachers reported to this negative interdependence. On the one hand, teachers expressed their difficulty in framing errors positively during learning activities (theme 4, code 15b). On the other hand, teachers stated that bad grades must be used to penalise errors while evaluating a performance task (theme 4, code 15a).

This ambivalence may be explained considering that educational systems serve two different functions, educational and selective. The educational function assures that all students have access to the same opportunities and the same level of education. In contrast, the selective function is aimed at rewarding and tracking students according to their performance (Darnon et al., 2009). Teachers have, therefore, a double role while teaching: to educate and to select (Butera et al, 2021). The educational role and expression of the educational function of school are best pursued by using formative assessment (e.g., Black & Williams, 2018). The selective role, expression of the selective function of education, is achieved through normative grades, which allows for sorting and selecting the best students (Autin et al., 2015; 2019).

Accordingly, our findings suggested that teachers recognized the hindering effect of the grading system when their instructional goal is to support students' learning. In this case, teachers reported that they have to make an extra effort to stress the pedagogical meaning of errors when using grades, by developing particular teaching strategies (Theme 7). On the contrary, other teachers said that errors must be considered while grading: only deserving students should be positively graded, whereas students who make errors for whatever reason

should receive a bad grade. In this way, teachers fulfil their selective role, also risking perpetuating a negative meaning of error as an event that should be avoided.

For this reason, daily assessment of homework, tests, and worksheets are examples of classroom activities that should be evaluated through formative assessment (Wou & Yao, 2019), which purpose is to improve students' learning by giving regular formative feedback on their learning development. Formative assessment requires teachers to highlight possible errors, frame them as useful for learning and provide immediate and clear feedback on how students could improve their work (see Heritage, 2010; Matteucci et al., 2019).

Limitations and Future Research

The first limitation of this study is that the data collection was based on interviews only. The teachers in the sample were not observed, which limited the possibility of exploring teachers' practices with a triangulation of methods. Future research on this topic should also access teacher practices and combine observational results with interviews or focus groups.

The second limitation refers to the sample. Teachers self-selected into this study by voluntarily agreeing to take part in interviews, indicating they likely had a pre-existing concern with errors and evaluation; possibly, they were the teachers who had already critical views of these issues. Furthermore, because of the wide range of teacher profiles (school level and subjects), we could not analyse the data by the type of subject taught. It is reasonable to argue that errors might bring different meanings and consequences depending on the subject. Future research could examine and compare various beliefs and error-handling strategies considering the school subjects.

The third limitation concerns the focus only on teachers' points of view and not on students' beliefs. Some of our results described teachers' beliefs about the students' perspectives without any corresponding insight into the students' thoughts and beliefs. Future

studies should also explore students' beliefs related to errors and evaluation to combine and compare the teacher's and the students' beliefs.

Finally, since evaluation emerged as an essential feature of the school system that can be experienced negatively by teachers, a greater exploration of this issue, which was not possible in this research, could further enrich the picture presented by these findings. The adverse effects of grading on teachers' supportive error handling strategies could also be explored through experimental studies, which compare, for instance, formative assessment and normative grading.

Conclusion

Teachers contribute to establishing an error-friendly environment with their error-handling practices. This study provided results on how teachers' practices are linked with their beliefs about errors and influenced by structural features of the education system (i.e., normative grading). Findings documented the complexity of teachers' beliefs about errors (e.g., their pedagogical, sanctioning, and threatening meanings), which is mirrored in the practices they adopted to deal with students' errors. Furthermore, our results shed light on the negative interdependence between errors and grades and revealed that this interdependence might contribute to challenging teachers in promoting a pedagogical meaning of errors during classes.

Chapter 7

Error handling in the classroom: an experimental study of teachers' strategies to foster positive error climate[4]

Abstract

The present research investigated the possibility to foster positive classroom climate, achievement emotions, and adaptive beliefs about errors by manipulating teachers' error handling strategies. Through a pre-post experimental design, teachers' error handling strategies were manipulated during a fictitious lesson in the primary school context. The experimenter, who was presented as an external teacher, carried out the lesson using positive and supportive error handling strategies (experimental condition) or neutral error handling strategies (control condition). The aim was to test differences in pupils' perceived error climate, achievement-related emotions and error beliefs comparing the two conditions. 108 fifth grade primary school pupils took part in the research. The main results revealed that dealing with pupils' errors using a constructive and encouraging strategy that supports them in learning from their errors (positive error handling) increased, compared with a neutral error handling, their perception of being in a trustful and supportive learning climate. This study represents the first experimental attempt in which error-related teaching strategies have been directly manipulated to identify their causal impact on primary school pupils' perceived error climate.

Keywords: errors handling, error climate, teachers, primary school, emotions.

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Introduction

"Your best teacher is your last mistake" is a figure of speech used in different cultures. The idea that learners can learn from their mistakes carries the positive connotation that errors are viewed as an unavoidable part of human life and can be used to improve skills and knowledge. Errors, however, have been defined as "an individual's behaviour or decision that differs unintentionally from a certain norm, prevents the attainment of a specific goal, and it is judged to be incorrect" (Grassinger & Dresel 2017, p. 61). If applied to the school context, this definition highlights the detrimental role of errors in the pursuit of set learning goals and the consequent negative evaluation, namely poor grades, from teachers. Accordingly, it is common practice for pupils to hide errors during the learning process. Several studies, however, have shown that errors and failures can be considered as the starting point of a deeper learning process, both in educational (e. g., Bray, 2011; Kapur, 2009; Zamora et al., 2018) and organizational contexts (Keith & Frese 2005; Rausch et al., 2017). Errors have personal and social connotations and how they are perceived and interpreted depends on individual and situational features (Billett, 2012). Thus, the probability that learners learn from their mistakes is higher when they hold constructive beliefs regarding making mistakes (Tulis et al., 2018) and when errors are positively framed in the environment. Research showed that how errors are evaluated and used in learning activities is associated with specific "error cultures", either adaptive or maladaptive to learning (e.g., Oser & Spychiger, 2006). Furthermore, perceiving a supportive and constructive "error climate" affects individuals' adaptive reactions following errors (Steuer et al., 2013).

As argued by Mercer and Littleton (2007), learning is a social and communicative process and teachers have a central role in fostering communication and the relation with students during the daily learning activities. Teachers can support and help students to actively participate in the lesson and to change and correct their mistakes and misconceptions

through dialogue (Alexander, 2000). For instance, mathematics teachers can use several strategies to fruitfully discuss students' mistakes during classroom interaction, providing the opportunity to learn instead of evaluating them (Ingram et al., 2015).

In this study, we focused on the role of teachers in providing students with efficient and supportive feedbacks on mistakes that, in turn, affect the students' perception of error climate (Tulis, 2013). Therefore, the present study aimed at enriching the research on the relationship between teachers' practices focused on students' mistakes (Santagata, 2005; Tulis, 2013), as well as on students' perceptions, beliefs and emotions. More precisely, the main research question addressed how different error-related teaching strategies (namely supportive/positive and neutral) could lead to a difference in pupils' perceived error climate, achievement emotions and error beliefs. In order to do that, an experimental manipulation created *ad hoc* for this research was carried out in primary schools. To the best of our knowledge, this is the first study that experimentally manipulates the teachers' strategies focused on managing the students' errors (error-handling strategies). Furthermore, this study tests these effects on primary school pupils, a sample rarely investigated by previous research on error climate.

In the next three sections, we present a concise literature review on error climate, its related personal and contextual features, and the role of the teacher in creating it. Then, we present the rationale, methodology and results of the present research. In the last section we discuss the findings together with their theoretical and practical implications.

Errors in Learning and Error Climate

A mistake occurs when there is a mismatch between the results of a student's action and the student's or teacher's expectations (Grassinger et al., 2015). Such a mismatch has been considered as the starting point of a self-regulation process. Indeed, the perception of an error first leads to an affective reaction towards the error necessary to appraise the situation,

followed by a regulation process needed to maintain sufficient levels of motivation. Both emotional changes and motivational regulation then trigger cognitive and metacognitive activities that, in turn, promote adequate strategies to face and overcome mistakes (Tulis et al., 2015). However, the whole process (in its emotional, motivational, and cognitive aspects) may be affected by contextual features and personal characteristics that could increase or reduce the possibility of learning from mistakes. Errors, indeed, may help students to develop more profound knowledge (see Kapur, 2009; Metcalfe, 2017), but at the same time, errors may have a demotivating effect on students (Weinert, 1999), resulting in less learning gains.

Extant research suggests that contextual features, such as error climate, have an impact on the possibility to learn from errors. Error climate is defined as the way students' errors are used, treated and evaluated during the learning process (Steuer et al., 2013). During the class activities, errors can be conceptualized as necessary and essential for learning, and they can be used as an instrument to develop knowledge in an emotionally safe and trustful learning environment (Tulis, 2013). In this case, a constructive, encouraging, positive classroom error climate is established. On the contrary, an unfavourable or adverse error climate emerges when supportive communication on errors between the teacher and learners is lacking, and students focus on being negatively evaluated for their mistakes (Tulis, 2013).

Several studies showed that positive error climate is related to affective reactions in students (increasing enjoyment, satisfaction, and pride; Tulis & Ainley 2011) and their error-related reactions (Steuer et al., 2013). Other studies found a relationship between dealing positively with mistakes in a supportive context and other learning-related outcomes, such as students' self-efficacy and joy (Kreutzmann et al., 2014), students'positive learning orientation and lower fear of making mistakes (Rach et al., 2013; Zander et al., 2014), students' motivation and positive learning outcomes (Käfer et al., 2019). Moreover, better achievement in mathematics was associated with students' perception of positive error

climate, and a small but significant correlation between error climate and achievement was found, both at the student and classroom levels (Steuer & Dresel, 2015).

The Role of Teachers in Fostering a Supportive Error Climate

Studies on classroom climate (Jennings & Greenberg, 2009), classroom emotional climate (e.g., Reyes et al., 2012) and classroom goal structure (e.g., Meece et al., 2006) pointed out the importance of teachers' strategies and practices in promoting (or not) positive, emotionally higher and mastery-oriented learning environments, which can foster motivation, positive emotions and achievement in students (e.g., Murayama & Elliot, 2009; Stuhlman & Pianta, 2009). The literature on feedback and formative assessment (e.g., Black & William 1998; 2009; Brookhart, 2017) highlighted that teachers may improve the learning process through effective feedback aimed at reducing "discrepancies between current understandings and performance and a learning intention or goal" (Hattie, 2009, p.175). Finally, the literature on argumentation pointed out that teachers should support students to understand and change their misconceptions and mistakes, through different practices such as dialogic teaching (Alexander 2000; 2006) and dialogic methods (see, Mercer, 2009). As expressed by Carugati and Perret-Clermont (2015), argumentation fosters students' cognitive development and knowledge construction, and according to Greco and colleagues (2017) teachers can actively help students to develop their points of view.

To sum up, the role of the teacher is crucial in creating an efficient learning context. Indeed, teachers' positive error handling strategies are a particular kind of feedback, focused on errors, that provide students with deeper analytic dialogue on misconceptions through supportive and proper reactions. Furthermore, according to Schleppenbach and colleagues (2007), by dealing appropriately with students' errors and telling them not to be afraid of errors, teachers can create an environment in which students are comfortable in making mistakes.

The empirical research about teachers' error management practices is still limited. An important contribution (Tulis, 2013) has studied and subdivided teachers' reactions in response to errors into two clusters: (a) maladaptive (or negative) responses to students' errors (such as ignoring mistakes, criticizing students, redirecting the question to another student, humiliating/laughing and showing disappointment), and (b) adaptive (or positive) responses to students' errors (i.e., discussing errors with the whole class, asking for a correction to the student him/herself, waiting for the correct reply, emphasizing the learning potential of errors and preventing negative reactions to a student's mistake from classmates). Following these results, this author argued that students show different attitudes toward errors based on how teachers handle the mistakes in their class, and that the teacher's tolerance toward error may also have a long-term effect on student attitudes toward (learning from) errors. More recently, Käfer and colleagues (2019) found that teachers' attitude toward mistakes, teachers' responses to student mistakes, and students' perception of the usefulness of mistakes for learning are related to students' individual achievement in an English as foreign language class. Furthermore, the same authors concluded that the students' perceptions of teacher's error-friendly attitudes and responses promote their motivation and achievement.

Students' Beliefs about Errors and Emotional Reactions

Beyond contextual features (such as the teacher's attitudes towards errors and the error climate addressed in the previous paragraph), other variables can be considered to explain the learning-from-errors process, namely students' beliefs about errors and emotional reactions. In this vein, Tulis and Ainley (2011) found a significant association between students' orientation to learning from errors and their on-task emotions after success and failure experiences, thus suggesting that perceiving errors as an important part of the learning process can foster positive emotional reactions in students after making mistakes. Previously, believing that errors are essential and beneficial for one's own learning and improvement was

found to affect the self-regulatory strategies adopted in the learning process (Keith & Frese 2005). Likewise, adaptive error beliefs have been shown to foster more adaptive reactions following errors in different domains, beyond students' academic self-concept and mastery goal orientation, and to act as a mediator in their relationship (Tulis et al., 2018).

Beyond students' beliefs, emotional reactions to errors and failure have been found to moderate the learning-from-errors process (Tulis et al. 2015). According to these authors, emotions lead to complex changes in both the affective and cognitive aspects of the students' reactions and are a necessary condition for persistent task engagement in the face of obstacles and for learning from errors in general (Tulis et al., 2016). This idea is also supported by the control-value theory of achievement emotions, which has shown that students' achievement emotions influence learning and achievement by affecting learning-related self-regulated processes (e.g., Pekrun, 2006; Pekrun & Perry, 2014).

The Present Study

This paper aims at investigating whether teacher's positive error handling strategies (i.e., adaptive, constructive, and supportive) may impact pupils' perceived error climate, error beliefs and achievement emotions. The first contribution of the present study is to provide an experimental test of this relation. Therefore, the teacher's strategies in dealing with students' mistakes were experimentally manipulated during a lesson conducted by an experimenter who was introduced as a teacher during a regular class. To the best of our knowledge, only a few studies used a quasi-experimental design, based on training teachers and then observing them during their lessons, although they did not directly manipulate the teacher's strategies (Heinze & Reiss, 2007; Rach et al., 2013). The rest of the existing research is based on correlational or observational methodologies (Käfer et al., 2019; Santagata, 2005; Steuer et al., 2013; Tulis, 2013; Tulis at al., 2018).

Second, the literature about error climate has mainly focused on secondary school contexts (Käfer et al., 2019; Rach et al., 2013; Spychiger et al., 2006; Steuer et al., 2013; Steuer & Dresel, 2015; Tulis et al., 2018), and only a few studies (Kreutzmann et al., 2014; Zander et al., 2014) were conducted in primary schools. Since, teachers are believed to foster a positive error climate through their feedback, behaviour, and responses, studying how teachers deal with students' errors could be even more interesting in those grades in which they manage all the classroom aspects (i.e., teaching, administration, relationship), and are more presents with the students in class, i.e., in primary school.

The study was carried out based on an experimental manipulation (detailed in the procedure section), that opposed positive handling (experimental condition) vs. neutral handling (control condition) of primary school pupils' errors during a lesson in class. In a pre/post-test design, we analysed the impact of these two error management strategies on the pupils' perception of the error climate established in the class, their beliefs about errors and their achievement emotions.

Based on the literature reviewed above, we formulated three hypotheses:

H1: We expected a more positive pre/post-test difference in perception of error climate in the positive handling condition than in the neutral handling condition.

H2: We expected a more positive pre/post-test difference in error beliefs in the positive handling condition than in the neutral handling condition.

H3: We expected higher perceived enjoyment and lower anxiety in the positive handling condition than in a neutral handling condition.

Method

Participants

To determine the sample size, we conducted a power analysis using G*Power 3.1 (Erdfelder et al., 1996). First, we considered the Tulis's (2013) findings since this paper

investigated perceived error tolerance by the teachers, students' attitude towards errors and covering up errors. Although this study is correlational, whereas ours is experimental, it is acceptable to use the effect size based on correlations for estimations related to experimental design (Perugini et al., 2018). Thus, we considered the three effects sizes that could be found in this study. The range of the effect sizes was d = 0.54 - 1.12 (median d = 0.58, medium effect, Cohen 1988). The power analysis computed with the smallest effect size (0.54) we found, to be on the safe side, indicated that a total sample of 48 participants was needed to detect a similar effect size, using a repeated-measures ANOVA with two measurements (r = .50), with 95% of power and alpha error probability set to .05. Second, we collected the effect sizes of studies with quasi-experimental design, similar to ours, in which teachers' error-related strategies were manipulated through teachers' training instead of direct manipulation. Rach and colleagues (2013) found significant results on affective teacher support and students' fear of making mistakes, while Heinze and Reiss (2016), using the same questionnaire as Rach and colleagues, found an impact also on cognitive aspects of teacher behaviour in mistake situations. The range of the five effect sizes found in these studies was d = 0.23 – 0.67 (median d = 0.36, small effect). The power analysis computed with the median effect size we found indicated that a total sample of 104 participants would be needed to find a similar effect size with 95% power using a repeated-measures ANOVA with two measurements (r = .50), with alpha at .05. Based on these results, we decided to recruit about 50 pupils for each condition, enough to detect a small-medium effect size, and to oversample to allow for drop-out, missing data and invalid questionnaires.

One hundred and sixty-one pupils from five public Italian primary schools, in the same Northern region in Italy (Emilia-Romagna), were enrolled in the study. Participation was voluntary, and a written consent form was required from the participants' parents. Twenty pupils did not have the consent form for taking part in the research, and, due to the pre-post

test design, we lost 33 participants because pupils missed one of the two parts of the experiment. Therefore, one hundred and eight (N = 108) fifth-grade pupils were considered for the analyses, belonging to seven classrooms ($M_{pupils\ per\ class}$ = 15.42, SD = 6.29, range = 5-22). The mean age was 10.38 years, SD = 0.54, and 53% were male. In order to divide the sample in the two conditions, each classroom was randomly assigned to one of the two experimental conditions before the data collection started: three classrooms in the neutral handling condition (composed of 22, 19, 22 pupils respectively), and four classrooms in the positive handling condition (composed of 15, 15, 10 and 5 pupils respectively). Classroom composition was not altered, and pupils participated in the study in their regular classroom; it should be noted that pupils in a classroom do not change as a function of subject or level as in other countries. The positive handling condition had a smaller number of pupils because of the composition of each classroom and only 45 pupils completed all the pre- and post-test measures. The two groups were comparable, since we did not find any significant difference between their characteristics. Table 1 shows additional information about the two groups' composition and the results of chi-square and t tests.

Table 1

Composition and Characteristic of the Experimental (positive handling condition) and Control (neutral handling condition) Group, Results of Chi-square Test and T-Test for the Difference Between the Groups

	Experimental group-positive handling condition	Control group-neutral handling condition	χ^2 (p)	t (p)
Classroom *N*	4	3	/	
Age Mean (*SD*)	10.32 (0.51)	10.43 (0.56)		1.11 (.269)
Gender *N* (%)			.209 (.648)	
Male	23 (51.1)	35 (55.6)		
Female	22 (48.9)	28 (44.4)		
Pupils *N* (%)	45 (41.7)	63 (58.3)	/	/
SpLD certifications *N* (%)	2 (4.4)	1 (1.6)	.793 (.373)	
Pupils born in Italy *N* (%)	41 (91.1)	59 (93.7)	.247 (.619)	
Spoken language *N* (%)			1.116 (.572)	
Italian speaking pupils	40 (88.9)	54 (85.7)		
Foreign language pupils	3 (6.7)	3(4.8)		
Bilingual pupils	2 (4.4)	6 (9.5)		

Note: $p < .05$. SpLD certifications = pupils with Specific Learning Disabilities certifications (e.g., dyslexia), issued by the National Health System.

Procedure

The Ethical Board of the first author's university approved the study protocol (protocol number 0017377). To manipulate the teacher 's error handling we created a script based on Tullis's (2013) findings of video-recoded lessons in Germany, and on Santagata's (2005) results concerning Italian teachers' error handling strategies. The script, explained in detail below, was carried out by the experimenter during a fictitious lesson. The experimenter was presented by the classroom teacher as an external teacher expert in the lesson subject. The lesson was about the "Constitution of the Italian Republic", a topic not related to either literature or science-related subjects, to avoid a gender stereotype effect (Flore & Wicherts, 2015). This subject is part of the school program, and in this respect, it was relevant and realistic. The lesson consisted of 10 slides (created with PowerPoint) in which the experimenter explained the Italian Constitution history and characteristics. The lesson lasted for one hour. During the lesson, to allow for pupils to make mistakes, the experimenter asked different questions to the whole class or to a specific student. A maximum of 50 questions was asked during the lesson. The experimenter asked a set of pre-determined questions during the lesson (from one to three for each slide), as well as follow-up questions that came out from the discussion. The experimenter bias was limited through several strategies, namely, the standardization of the whole manipulation (sentences, slides and comments were set in advance and learned by heart), the observation of the procedure during the lesson by a research assistant, and the analysis of the audio recordings of the lessons, which confirmed that the planned procedure was followed in each class. The lesson was carried out in two different ways, according to the experimental conditions: a "positive handling" condition and a "neutral handling" condition.

Positive handling condition. The script consisted of an introduction, in which the experimenter said: "You can learn from your mistakes, so it is important to try responding

even if you are not sure about the right answer" and by five different error handling strategies, namely:

Discussion with the whole class: The experimenter starts a discussion with the whole class, asking the whole class for (different) solutions. For example: "Ok…Let's see if we will find the right answer together."

Correction by the student him/herself: The experimenter repeats/rephrases the question and/or gives a hint to the pupils in order to get the correct answer. For example: "Think hard and try again!"

Proper wait-time: The experimenter waits at least five seconds without reformulating the question or giving a hint; this wait-time gave pupils a better chance to answer the question as it gave them the possibility to think and formulate their answers.

Emphasizing the learning potential: The experimenter highlights the pupil's active contribution positively and emphasizes the learning potential of the mistake. For example: "It is not exactly right, but, thanks to your answer, I have understood that something is not very clear, so now I will try to clarify this point.".

Impeding negative classmate reactions: The experimenter stops every kind of embarrassing reaction after a pupil's error, such as classmates' jokes and laughers.
These strategies were adapted from Tulis (2013), in which the author observed Germany teachers using these practices, coded them as "adaptive" and found correlation with students' perception of error-friendly environment in classrooms.

Neutral handling condition. The neutral script consisted of the following introduction: "You can answer my questions, but, please, answer only if you are sure that your answer is correct, otherwise you may make many mistakes!", and by three kinds of responses, namely:

Ignoring mistake: The experimenter ignores the mistake, switches to another topic without any comment.

Redirecting the question to another student: The experimenter picks another pupil to correct the mistake made by the first pupil (the so-called "Bermuda triangle of error correction", Oser & Spychiger, 2006).

Focus on the wrong answer: The experimenter replies to the pupils saying the answer is not correct. Example: "No. It is incorrect!"

For example: "No, it is wrong! – and switching to another pupil: "Can you reply to my question?".

The first two responses were adapted from Tulis (2013) and the third was added by the authors. We chose to add this last one based on Santagata's findings (2005) on the most common teachers' mistakes-handling strategies observed in Italian mathematic lessons, that the author called "aggravation". This strategy is quite often used in the Italian classrooms, thus we decided to add "Focus on the wrong answer" to the neutral condition instead of using other maladaptive strategies identified by Tulis (2013) and by other researchers (e.g., Oser & Spychiger, 2006), such as "Humiliate", "Expression of disappointment", "Criticizing students". These last strategies might cause great discomfort and stress in the pupils. Since the manipulation was carried out in Italian context, in which students are used to receiving negative mistakes-responses (Santagata, 2005) we believe that the three responses in our neutral condition can be considered less negative than the responses coded by Tulis (2013). Thus, we called the condition "neutral error handling condition".

All the lessons were audio recoded and observed by an external observer who collected information about the pupils' participation to the lesson (counting the number of pupils who raised hands after the questions) and to monitor the error handling strategies used by the experimenter.

One week before the lesson, the pupils filled in a questionnaire (pre-test) and, at the end of the lesson, the pupils were asked to fill in a post-manipulation questionnaire (post-test), both administered by a research assistant. To match the pre-post tests and questionnaires without disclosing the pupils' identity, we used an anonymous coding system. At the end of the data collection, the pupils were fully debriefed.

Pre-test Measures

Demographics. Students were asked to provide information about their gender, age, the class attended, nationality, the spoken language and the one mostly used at home (to ascertain their ability to understand the wording of the items).

Perceived error climate questionnaire-short version- ECQ_pre (16 items). The questionnaire is designed to assess the students' perception of teachers' affective and behavioural responses to students' errors, the use of error in the learning process and the classmates' behaviour. It includes 16 items with a 4-point Likert agreement response ranging from 1 "strongly disagree" to 4 "strongly agree" (e.g., "During the lesson, for our teacher it is not a problem at all if someone makes a mistake"; "During the lesson, we deeply analyse the errors"). The items were preceded by a statement asking pupils to answer the questionnaire by thinking about the climate established by their main teacher. This short version was created specifically for primary school pupils, based on the 31-item scale created by Steuer, and colleagues (2013). In a pilot study, the short version was translated from German to Italian with the forward-backward procedure and was administered on a sample of Italian primary school children (N = 305, 10 years old, 54% male). The questionnaire (used as a single factor) showed a good reliability (α = .75).

Error Beliefs Questionnaire- EB_pre (Tulis et al., 2018). This 5-item questionnaire is aimed to assess the students' beliefs about errors on a 4-point Likert scale from 1 "strongly

disagree" to 4 "strongly agree" (example items: "Errors are important for my own learning"; "I can learn a lot from my mistakes"). The scale was translated into Italian by the authors.

Post-test Measures

Error Climate Questionnaire, ECQ_post. The same questionnaire as in the pre-test was administered. In this case, items referred to the (fictitious) lesson just completed, instead of referring to the lessons of their teacher.

Error Beliefs Questionnaire, EB_post. The same questionnaire as in the pre-test was administered in the post-test.

Achievement Emotions Questionnaire-AEQ-ES (Lichtenfeld et al., 2012; Italian version: Raccanello et al., 2019). The scale assesses three main emotions: boredom, anxiety, and enjoyment. It comprises three sections: the emotions felt during the lesson, the emotions felt during the homework and the emotions felt during a test. In the current study, we used only the section about the emotions felt during the lesson, focusing on anxiety and enjoyment (8-item scale, four items for each emotion, e.g., "During this class, I worry that everything is too difficult for me" and "I enjoy this class"). For each item, the scale presents schematic drawings of faces corresponding to the level of emotional intensity to be rated on a five-point Likert scale, ranging from 1 (not at all) to 5 (very much).

Manipulation check. To check whether participants correctly perceived the error manipulation condition, positive vs. neutral, they were asked to answer the following question: "During this lesson, the teacher said that errors are important to learn something new" (Yes/No).

Results

The analyses were performed using Mplus version 8 (Muthén & Muthén, 2017) and SPSS version 21.0. Descriptive statistics, internal consistency, bivariate correlations and

intraclass correlations (ICCs) for all the variables (pre and post-test) are presented in Table 2. All the tests were 2-tailed.

Manipulation Check

A Chi-square test was performed to test if the manipulation was perceived as intended. The result showed a significant effect, $\chi^2(1) = 12.67$, $p < .001$; as expected, in the positive handling condition 41 out of 45 pupils replied "*yes*" to the question "During this lesson, the teacher said that errors are important to learn something new", while in the neutral condition 25 pupils out of 65 replied "*no*". Thus, this finding suggests that the participants understood the positive condition. However, it is important to note that in the neutral condition, not all the pupils reported the expected response. A plausible explanation may be the social desirability of the question, that reflects the commonly purported belief on mistakes, namely that errors can improve learning, or the acquiescence bias which leads respondents to answer items with affirmative replies, independently of their content.

Descriptive and Preliminary Analyses

First of all, as pupils are nested in classes, we calculated the intraclass correlations of all the variables to estimate the degree of nonindependence within classes, using Mplus 8 (Muthén & Muthén, 2017). ICCs ranged between .009 and .136, all *ps* > .05. However, an ICC higher than .05 could mean that the independency of the observations (pre-post test) is violated. Thus, we decided to perform a Linear Mixed Model analysis (Field, 2013) to avoid the alpha-error-inflation (Stevens, 1996). It is important to note that the ICC scores of the main dependent variables decrease from before to after the manipulation. A possible explanation may be that pupils in the same classroom are differently affected by the manipulation and that the classrooms belonging to the same condition were more similar after the manipulation than before because of the manipulation itself.

Table 2
Descriptive Statistics and Bivariate Correlations Among the Dependent Variables

Variable	*M*	*SD*	1	2	3	4	5	6
1.Error beliefs_pre	3.22	0.39	-	.38**	.67**	.13	.22*	-.12
2.Error climate_pre	3.06	0.32		-	.34**	.48**	.12	-.13
3.Error beliefs_post	3.25	0.46			-	.14	.19	-.09
4.Error climate_post	3.21	0.37				-	.21*	-.19*
5.Enjoyment	3.52	1.02					-	-.22*
6.Anxiety	1.26	0.49						-
Cronbach's alpha	-	-	.58	.72	.76	.75	.91	.50
ICC	-	-	0.103	0.118	0.045	0.050	0.136	0.009

Note. N = 108 students from 7 classrooms. Error beliefs_pre = Error beliefs questionnaire administered at the pre-test; Error climate_pre = Error climate questionnaire administered at the pre-test; Error beliefs_post = Error beliefs questionnaire administered at the post-test; Error climate_post = Error climate questionnaire administered at the post-test. ICC = Interclass Correlation and level of significance of variance between subjects.**p< .05; **p< .001*

Perceived Error Climate

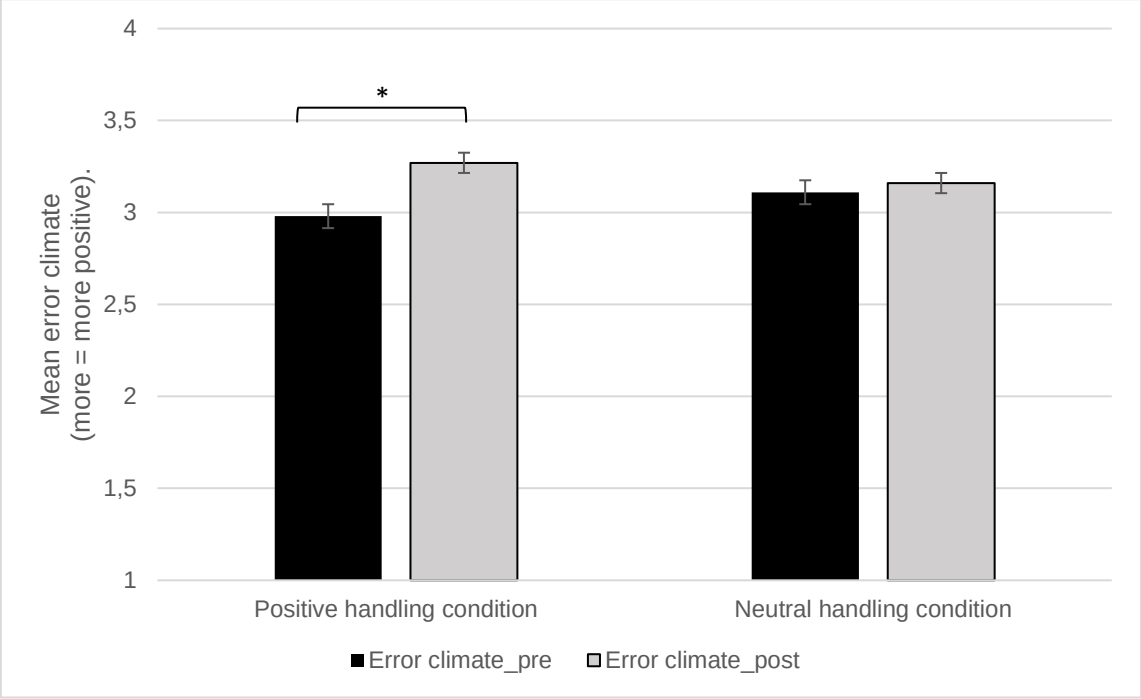
In order to control for the effect of the nested data we ran a Linear Mixed Model analysis in SPSS. This analysis considers the hierarchical structure of the data, controlling for the belonging to a specific class for all our dependent variables. As for Error Climate, in order to understand if the classrooms significantly affect the fixed effect of repeated measures and conditions on the error climate questionnaire scores, we compared two different models: one in which the random effects are not allowed (like a repeated -measure ANOVA, model 1) with one in which we allow the variation of the intercepts between the classrooms (model 2). The analysis showed a significant variance of the intercept across the classrooms, $\chi 2$ (1) = 7.50, $p < .01$. Indeed, the difference of fits between the two models was significant, resulting in better fit indices for the model 2, *-2LL* = 158.516, *df* = 6, AIC = 162.516 than for the model 1, *-2LL* = 166.021, *df* = 5, AIC = 162.516. Furthermore, we can state that this difference is significant because it is higher than the critical value of the chi-square with 1 df (3.84, $p < .05$, 6.63, $p < .01$) (Field, 2013). Therefore, we included in our analysis the random effect due to the variance of the intercepts between the classrooms. The Wald statistic, $z = 1.174$, $p = .240$,

was not significant but we did not look at this value since, according to Field (2013), this statistic is not as reliable as the *-2LL* statistic.

Controlling for the random effect, the analysis showed a significant main effect of the repeated measure, $F(1, 205.82) = 14.03$, $p < .001$, $d = 0.49$[5] , resulting in a more positive error climate after the manipulation ($M = 3.21$, $SD = 0.37$) than before the manipulation ($M = 3.06$, $SD = 0.33$); as well as a non-significant effect of condition, $F(1, 4.51) = 0.16$, $p = .709$. However, the hypothesized interaction effect between the condition and the repeated measure was significant, $F(1, 205.82) = 6.37$, $p = .012$, $d = 0.83$[1]. The Bonferroni post-hoc test revealed a significant difference in the positive condition, resulting in a more positive perceived error climate after the manipulation, $M = 3.27$, $SD = 0.40$, compared to before, $M = 2.98$, $SD = 0.36$, cf. Figure 1.

Figure 1

Mean Error Climate as a Function of Conditions (positive handling vs. neutral handling) and Repeated Measure (Time: pre-test and post-test). Error Bars Represent Standard Errors



Note. ***** $p < .05$

[5] For the Linear Mixed Model effect size computation see Westfall Kenny and Judd (2014).

Errors Beliefs

To test the effect of the manipulation on the pre-post difference in pupils' beliefs about errors we performed the same Linear Mixed Model analysis. The analysis showed that model 2 significantly improved the fit, *-2LL* = 250.537, *df* = 6, AIC = 254.537, compared with model 1, *-2LL* = 261.010, *df* = 5, AIC = 263.010. The intercept across the classrooms varied significantly, $\chi 2$ (1) = 10.47, $p < .01$. Considering model 2, neither the main effect of time (repeated measure), $F(1, 205.89) = .338$, $p = .562$, or the main effect of condition, $F(1, 4.60) = .826$, $p = .409$, were significant. Also the interaction was not significant, $F(1, 205.89) = .014$, $p = .907$.

Achievement Emotions

Achievement emotions were only measured at the post-test. The Anxiety scale showed low reliability ($\alpha = .50$) and a non-normal distribution ($M = 1.26$, $SD = 0.49$, Skewness = 3.38, Kurtosis = 13.29). This is probably due to a floor effect on three items out of four. Thus, we decided to run a non-parametric test for this variable. On the contrary, a Linear Mixed Model was applied to analyse the Enjoyment sub-scale.

As far as Anxiety is concerned, we used the Mann-Whitney non-parametric test to compare the level of the Anxiety score between the two conditions. The analysis showed a significant difference between the two groups, $U = 1.127$, $z = -2.00$, $p = .045$, $d = 0.39$[6], resulting in a higher level of anxiety in the neutral condition ($Mdn_{rank} = 59.11$) than in the positive condition ($Mdn_{rank} = 48.04$). This result has to be prudently interpreted, since the scale had a low reliability.

As for the enjoyment, first of all, we compared a first model without considering the cluster (model 1) with a model in which we allow the variation of the intercept (model 2). The fit of model 2 was better, *-2LL* = 302.353, *df* = 4, AIC = 306.353, than the fit of model 1, -

[6] For the Mann-Whitney test effect size computation see Fritz Moris and Richler (2012).

2LL = 307.870, *df* = 3, AIC = 309.870. The difference between these two models was significant, $\chi 2$ (1) = 5.52, $p < .05$. Considering model 2, the results showed a non-significant difference on enjoyment, $F(1, 4.88) = 1.70$, $p = .251$, between the two conditions.

Discussion

In this study, we conducted an experimental test of the hypothesis that different teacher's error handling strategies may affect the pupils' perceived error climate, their personal beliefs about error and achievement emotions felt during a lesson. We created a pre-post research design, in which we manipulated the teacher's handling of errors and classroom management strategies concerning pupils' errors. Through a fictitious lesson, created ad hoc for the experimental manipulation, pupils' mistakes were managed in either a positive or a neutral way. Thus, during the fictitious lesson, the trained experimenter—in the role of the teacher—aimed to establish either a positive or neutral error climate, by following a script with different responses to pupils' errors. To test our hypotheses, we assessed differences in the perceived classroom error climate before and after the fictitious lesson (H1). Additionally, we also tested the pre-post change in pupils' personal error beliefs (H2) and, at the post test, the achievement emotions they felt during the lesson (H3).

Contributions

The main result of this research is that pupils in the positive handling condition perceived a more positive error climate after the lesson than before, to a greater extent than pupils in the neutral handling condition (H1). The theoretical model elaborated by Tulis and colleagues (2016), describes how individual and contextual features may affect the learning-from-errors process. Positive error climate is a central aspect of error-friendly environments and teachers have a pivotal role in establishing it. Our study, to the best of our knowledge, is the first one that experimentally demonstrated that specific teaching strategies, focused on

dealing with errors in a constructive and supportive way, can change the error climate in the classroom. This result is in line with previous studies concerning the link between teachers' error handling strategies, especially their feedback, and the error climate in their classroom (Tulis, 2013). However, in previous correlational research on the learning-from-error process (e. g., Tulis et al., 2016), causal claims about how error climate can be established in primary classroom environments were not possible. Indeed, most of the research on teaching and teachers' strategies have used observational methods and videotapes (e.g., Matteucci et al., 2015; Santagata, 2005; Tulis, 2013) or teachers' training on error handling strategies (e.g., Heinze & Reiss, 2007; Rach et al., 2013). Our approach allowed us to directly manipulate the handling of errors using a controlled experimental procedure, and such causal claims are possible in the present study. Therefore, this study contributed to fill the gap in the literature on the role of teachers' strategies in establishing a positive error climate in primary school classrooms.

Another contribution concerns the third hypothesis. We found a significant difference between the two conditions on anxiety, resulting in higher anxiety scale scores in the neutral than in the positive condition. This result could suggest that in the positive handling condition, pupils felt more comfortable during the lesson and they experienced fewer concerns regarding the difficulty of the contents. However, one must interpret this result prudently, since the scale used was not reliable and a floor effect on three items out of four suggested that the instrument was not appropriate for this study. Further research is needed to understand the relation between error handling strategies and achievement emotions.

Limitations

This study also has some limitations worth noting. Firstly, the second hypothesis was not supported. A possible explanation may be that personal beliefs, derived from experience and years of habituation, can be particularly resistant to change, especially by a time-limited

intervention (Murphy & Mason, 2006). For example, it has been found that students' personal beliefs (about malleable vs. fixed intelligence) changed over an 8-week workshop (Blackwell et al., 2007), but in a recent 3-day intervention program researchers were not able to induce a change in students' general beliefs about intelligence and effort (Lin-Siegler et al., 2016). Thus, it is plausible that, in order to induce a change in beliefs, a longer intervention could be required, thereby allowing a deeper analysis of personal beliefs systems (Grube et al., 1994)

An alternative explanation is that pupils responded to the questionnaire according to a social desirability bias, as in our society people are supposed to believe that errors are essential for learning. Further research is needed to investigate this issue in order to observe changes more accurately and also distinguish long-term modifications (for example, with a longitudinal study). Moreover, strategies to limit the potential effect of social desirability bias could be implemented.

Secondly, differently from our expectation, we did not find any difference on enjoyment between the two conditions and, due to the low reliability of the anxiety scale (H3), the hypothesis on achievement emotions need to be investigated in a future study, preferably with a different and more appropriate scale. Thirdly, our manipulation was introduced by the experimenter and thus the experimenter expectancy effect could have been at play. Of course, as noted above, the implementation of the manipulation was fully controlled through several techniques, such as, for instance, following a pre-determined lesson, using a fixed script for questions and the manipulation, audio-recording and assessing the manipulation with the help of an external observer; however, it was not possible to follow a completely double-blind procedure. This mandatory high standardization of the procedure led to another important limitation of the present study, namely the limited generalizability of the results. Indeed, the present research is based on a manipulation that simulates a fictitious lesson. We tried to create a context as similar as possible to the real classroom context, but the

presence of an external “teacher” and of the data collection procedure made the lesson different from that of a typical day. These two related limitations of our study may be addressed in further research in different way. For instance, it could be possible to focus on a daily lesson, studying the relationship between students and their regular teacher, combining qualitative and quantitative measures, applying a triangulation of methods. It would be also interesting to train regular teachers in error handling strategies analysing changes in the pupils during a classical lesson. Fourthly, the number of experimental groups (only seven classrooms) was not enough to run multilevel analyses. Although with Linear Mixed Model analyses we control for the random intercepts due to the hierarchical data, a further study with a higher number of classrooms needs to be conducted.

Finally, we focused only on a small part of the whole Tulis and colleagues (2016) learning-from-errors process. Thus, further research should explore the interconnections between personal features (e.g., errors’ beliefs, personal reactions towards errors, ability self-concept) and contextual features (e.g., error climate, classroom achievement goal structure, errors handling strategies) that are involved in the learning-from-errors process.

Conclusion

Beside these significant limitations, the present research enriched, we believe, the literature on error climate, with a particular focus on the primary school context, seldom studied so far, and by means of an original experimental design. Overall, our findings have theoretical implications, as they suggest that a supportive and constructive teacher’s handling of errors causally affects cognitive aspects involved in the theorized learning-from-errors process (Tulis et al., 2016). Considering these results at a more general level, the role of teachers’ practices in establishing an effective environment for learning, is supported. As argued by Mehan (1979) when the student’s reply is not correct, the interaction between the

student and the teacher can be extended and teacher's responses support and expand the discussion. Indeed, the positive error handling strategies selected in our manipulation, by providing pupils with prompts on their mistakes, solicited a deeper dialogue and discussion on misconceptions. Dialog and discussion may, in turn, lead to better learning outcomes, as suggested by literature on argumentation (see Alexander, 2006; Greco et al., 2017). Furthermore, the role of teachers in creating a positive and emotionally safe classroom climate has already been supported by a great deal of studies (e.g., Jennings & Greenberg, 2009) and we believe that our findings contribute to a better understanding of this process, showing the causal role of error-related strategies.

These considerations lead to some practical implications of this study. As argued by Furtak and Ruiz-Primo (2008) and by Pimentel and McNeill (2013), teachers should become aware of the relevance of promoting dialogue with students and a constructive climate about errors in the classroom in order to ameliorate the learning process. Specifically, better knowledge and awareness of the conditions under which using errors may ameliorate the learning process and the (formative) evaluation process (Matteucci et al., 2019) and may contribute to the improvement of the learning/teaching process. With this aim, teachers' professional training programs may promote teaching practices suitable to allow a safe and supportive environment, where positive and productive effects of error and failure may emerge (Kapur, 2009). In this vein, it is important to note that previous research on mathematical education, has shown that failure can be a tool for preparing students to benefit from subsequent instruction and that creativity is associated with making errors, which in turns positively influences learning in the longer term (Ziegler & Kapur, 2018). It is also worth noting that we found significant and sizeable effects through a short intervention (i.e., a 1-hour lesson); we thus consider that if regular class teachers systematically implement

supportive and constructive teaching strategies to deal with errors, they may potentially achieve a more fruitful and long-term impact on the establishment of a positive error climate.

In conclusion, future research should investigate further error-related situations in the classroom, for instance, the test situation, in which errors are more salient for the students. Previous research has demonstrated that grades have detrimental effects on students' learning and motivation (e.g., Klapp, 2015; Pulfrey et al., 2011; Pulfrey et al. 2013), even on primary school pupils (Hayek et al., 2017). Thus, it would be crucial to understand the interplay between error handling strategies and grading in evaluative situations.

Supplementary Materials[7]

Disentangling Perceived Error Climate Dimensions and Manipulation Check

We ran supplementary analyses to test whether the eight subdimensions of the Perceived error climate questionnaire were related to the manipulation check question ("During this lesson, the teacher said that errors are important to learn something new"). First, we checked the correlations between each subdimensions, the total score of perceived error climate and the manipulation check. As shown in Table S1, only the dimensions *Analysis of errors* and *Functionality of errors for learning* were significantly correlated with the manipulation check.

Table S1
Bivariate Correlations of the Perceived Error Climate Unique Factor, the Eight Subdimensions and the Manipulation Check

Variable	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Perceived Error climate unique factor (16 items)	-	.57**	.58**	.56**	.69**	.59**	.41**	.49**	.48**	-.13
2. Error tolerance by the teacher		-	.26**	.31**	.45**	.08	.04	.21*	.21**	.02
3. Irrelevance of errors for assessment			-	.06	.50**	.39**	.17	.10	.05	-.08
4. Positive support by the teachers				-	.30**	.21*	-.01	.38**	.40**	-.02
5. Absence of negative teachers reactions					-	.38**	.17	.13	.16	-.06
6. Absence of negative classmates reactions						-	.27**	.10	.07	-.02
7. Taking the error risk							-	-.04	-.11	.03
8. Analysis of errors								-	.46**	-.24*
9. Functionality of errors for learning									-	-.24*
10. Manipulation check										-

Note. N = 108 students from 7 classrooms. *$p < .05$; **$p < .01$

[7] These analyses are reported only in the dissertation since the paper has been already published

Second, we created a new Perceived error climate questionnaire variable excluding the four items belonging to these two subdimensions because they could be possible confounders of the main effect of the manipulation on the pupils' perception of the error climate. Then, following the same analytical procedure shown in the Result section, we ran a Linear Mixed Model using this new version of the perceived error climate as the dependent variable. We compared two different models: one in which the random effects are not allowed (Model 1) and one in which random intercepts are allowed (Model 2). The analysis showed a significant variance of the intercept across the classrooms, $\chi 2$ (1) = 5.09, $p < .05$. Indeed, the difference of fit between the two models was significant, resulting in better fit indices for Model 2, *-2LL* = 214.684, *df* = 6, AIC = 218.684 than for Model 1, *-2LL* = 219.780, *df* = 5, AIC = 221.780.

Controlling for the random effect, the analysis showed a significant main effect of the repeated measure, $F(1, 205.85) = 23.41$, $p < .001$, resulting in a more positive error climate after the manipulation ($M = 3.21$, $SD = 0.57$) than before the manipulation ($M = 2.96$, $SD = 0.58$); as well as a non-significant effect of condition, $F(1, 4.58) = 0.33$, $p = .592$.

Furthermore, the hypothesized interaction effect between the condition and the repeated measure was significant, $F(1, 205.85) = 5.54$, $p = .019$. The Bonferroni post-hoc test revealed a significant difference only in the positive condition, resulting in a more positive perceived error climate after the manipulation, $M = 3.25$, $SD = 0.43$, compared to before, $M = 2.86$, $SD = 0.39$.

Supplementary analysis of anxiety scale

As reported in the discussion section, the anxiety subscale of the Achievement Emotions Questionnaire showed not satisfactory reliability (r = .50). The low reliability was probably due to the floor effect of the four items of the questionnaire (see Table 1, Chapter 7) and a subsequent not normal distribution of the data. For this reason, we performed a non-parametric test to explore the effect of the experimental manipulation on the pupils' anxiety levels.

Another possible analytical strategy would have been to keep only one relevant item of the scale and test the hypothesised effect only on it. In our case, the anxiety scale included an item that was more relevant than the others (Item 4). The wording of this item was the most appropriate for measuring anxiety felt during the lesson. Indeed, this item stated: "During this lesson, I was worried because everything seemed too difficult to me", whereas the other three focus more on anxiety felt in waiting for the lesson, such as "When I think about this lesson, I feel nervous". These other items were not completely appropriate for the experimental manipulation for two main reasons. First, they referred to the lesson in a general way, whereas item 4 referred to a specific characteristic related to making errors ("…everything seemed too difficult"). Second, students attended the fictitious lesson only once, whereas the items referred more to a daily lesson, such as regular math or Italian lesson. Item 4 was also the only one that presented a lower floor effect (M = 1.60, SD = .93) as well as skewness and kurtosis values (1.70 and 2.90, respectively).

Therefore, we ran the Mann-Whitney non-parametric test again only with this item. The test replicated the results reported in the Result section of this Chapter. The analysis showed a significant difference between the two conditions, U = 1080, z = -2.02, p = .043, resulting in a higher level of anxiety (Item 4) in the neutral condition (Mdn_{rank} = 57.86) than in the positive condition (Mdn_{rank} = 47.12).

Chapter 8

Positive Error Climate Promotes Learning Outcomes through Students' Adaptive Reactions towards Errors[8]

Abstract

Errors are an integral part of the learning process and an opportunity to increase skills and knowledge, but they are often discouraged, sanctioned and derided in the classroom. This study tests whether students' perceptions of being part of an error-friendly classroom context (i.e., a positive classroom error climate) are positively related to students' learning outcomes via students' adaptive reactions towards errors. A total of 563 Italian middle school students from 32 mathematics classes completed a questionnaire on their perceptions of classroom error climate and their reactions towards errors. Students' math grades were used as indicators of their level of learning outcomes. A multilevel model showed that perceived classroom error climate was positively related to math grades via increased adaptive reactions towards errors. Our findings revealed that an error-friendly classroom context is associated with students' adaptive adjustment to errors and to better learning outcomes in mathematics.

Keywords: Error climate, Students' reactions, Middle school, Learning Outcomes, Multilevel.

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Introduction

Students make errors every day at school. The learning process itself occurs while learners engage in tasks that refer to knowledge beyond their mastery level (Vygotsky, 1978). Therefore, making errors should be considered as an integral part of the learning process and an opportunity to increase skills and knowledge (Bray & Santagata, 2014). However, the link between errors and evaluation and competition in school (Authors, in press) may increase the students' fear of erring (Grassinger & Dresel, 2017), and ultimately prevent learning.

The learning from errors model (Tulis et al., 2016) is an integrative theoretical framework encompassing the individual processes, personal and environmental features that may promote learning from errors. According to this model, error detection leads to a series of self-regulation processes (i.e., students' emotional arousal, motivational regulation, metacognitive activities), which may, in turn, promote (or not) learning. These processes are influenced by students' personal features (e.g., their error beliefs, Tulis et al., 2018) and their perceptions of the classroom environment (e.g., the perceived error climate, Steuer et al., 2013).

To date, scant empirical research has examined whether the perceived error climate is associated with students' learning outcomes (i.e., grades), via their self-regulated processes (i.e., adaptive reactions towards errors, Grassinger et al., 2018), and no study has tested this association in a comprehensive model, considering other personal features and perceptions of classroom environment facets, as theorised by the learning from errors model (Tulis et al., 2016). In addition, most studies based on the learning from errors model (Tulis et al., 2016) focused on German secondary schools only (e.g., Dresel et al., 2013; Steuer et al., 2013).

Therefore, we aimed to expand the literature in two ways. First, we empirically tested the association of perceived error climate with students' learning outcomes (i.e., grades) via adaptive reactions towards errors, analysed only once so far (Grassinger et al., 2018). In

particular, the unique contribution of the present research is that we tested this association in a comprehensive model, controlling for other personal (i.e., students' errors beliefs) and perceived classroom features (i.e., classroom goal structure). Second, we generalized the learning from errors model (Tulis et al., 2016) in another context than the German one by validating the Italian version of the scales related to the theoretical model (e.g., Dresel et al., 2013; Steuer et al., 2013; Tulis et al., 2018), and providing relevant results obtained in the Italian middle school context (i.e., grade 6-8).

Perceived Error Climate in the Classroom

Using errors as a steppingstone for learning may depend on how they are perceived within the teacher-student relationship during classroom activities. Several studies have shown that students' perceptions of their teachers' behavioural and emotional error-related responses impact their fear of failure and the use of errors as a learning opportunity (e.g., Heinze et al., 2012; Käfer et al., 2019; Spychiger et al., 1999; Spychiger et al., 2006). In the same line, other studies explored the role of teachers' error-handling strategies in conveying errors' meanings (e.g., Santagata, 2004), influencing students' errors (e.g., Rach et al., 2013; Tulis, 2013) and classroom climate perceptions (Author et al., 2020).

Teachers have a pivotal role in establishing what Steuer and colleagues (2013) defined as the perceived error climate, namely the error-related classroom climate that depends on how teachers frame, handle, and evaluate students' errors. Starting from the concept of error culture developed and studied in both organisational (Rybowiack et al., 1999) and educational contexts (e.g., Spychiger et al., 2006), Steuer and colleagues (2013) developed a new instrument to assess error climate. Differently from other scales (e.g., Spychiger et al., 2006), the perceived error climate questionnaire assesses only students' perceptions of classroom climate instead of mixing students' perceptions and students personal handling of errors.

The perception of error climate depends on how students interpret its subdimensions, which determine if they feel to be part either of an error-friendly environment (namely, positive error climate) or an environment in which errors are not tolerated (namely, negative error climate). The subdimensions refer to: Teachers' attitudes and behaviours towards errors (i.e., Error tolerance by the teacher, Irrelevance of errors for assessment, Teacher support following errors, Absence of negative teachers' reactions); classmates' reactions (i.e., Absence of negative classmate reactions and Taking the error risk); practical use of errors during learning activities (i.e., Analysis of errors and Functionality of errors for learning).

These eight subdimensions constitute a superordinate and uniform construct, namely the overall error climate (Steuer et al., 2013). Feeling part of an error-friendly environment has been shown to be related to students' higher achievement (Grassinger et al., 2018) and students' adaptive reactions towards errors (Steuer et al., 2013).

Adaptive Reactions Towards Errors

Students' reactions towards errors refer to the self-regulation processes triggered by error detection, and, in turn, determine if the learner enacts functional and proactive emotional responses and behaviours after making errors. Dresel and colleagues (2013) conceptualized two different reactions towards errors, namely affective-motivational and action reactions. The former refers to the students' positive emotions and high motivation maintained in facing errors, while the latter refers to the behaviours and actions carried out to overcome errors (Grassinger & Dresel, 2017). Several studies analysed the two reactions towards errors, showing that they represent two distinct constructs (Dresel et al., 2013; Grassinger et al., 2015; Grassinger & Dresel, 2017; Steuer et al., 2013, Tulis et al., 2018). Also, consistent with the predictions of the learning from error model (Tulis et al., 2016), one study (Grassinger et al., 2018) pointed out that adaptive affective-motivational reactions predict action reactions towards errors, but not the reverse.

However, little is known about the effect of both adaptive reactions towards errors on students' learning. To the best of our knowledge, only Steuer and colleagues (2013) found a relationship between the reactions towards errors and students' sustained effort in learning. In addition, only one study (Grassinger et al., 2018) tested the effect of adaptive reactions on learning outcomes, such as students' grades.

Error Beliefs

Maintaining high motivation and using efficient metacognitive processes after making errors also depends on personal characteristics, such as error beliefs, namely students' belief that it is possible to learn from errors (Tulis et al.,2018). The authors showed that error beliefs are related to more adaptive affective-motivational and action reactions towards errors. In the same study, the authors highlighted that error beliefs affect students' reactions towards errors beyond other personal characteristics (e.g., achievement motivation).

Differently from students' error climate perception that may change according to teachers' error-handling strategies (Authors, 2020), error beliefs tend to be a more stable personal characteristic (Tulis et al., 2018). For this reason, in the present study, errors beliefs are considered as a stable personal variable, used as control.

Classroom Goal Structure

In addition to perceived error climate, which relies on how errors are framed during learning activities, other classroom characteristics may impact students' likelihood to learn from their errors, such as their classroom goal structure (Bardach et al., 2020; Meece et al., 2006). Classroom goal structure refers to students' perceptions of teachers' goal-related messages shared with students during the learning activities (Bardach et al., 2020). Three main goal structures have been studied, namely mastery (the main goal is to properly master the task and the subject), performance-avoidance (the main purpose is avoiding showing one's

own incompetence), and performance-approach (the main purpose is to obtain good grades and outperform others; see Midgley et al., 2000).

Classroom goal structure is related to classroom error climate in three ways. First, they both concern students' perceptions of classroom characteristics. Second, classroom goal structure refers to achievement and learning, which depend on errors. Third, both constructs are related to teachers' attitudes and behaviours while teaching and managing the class. Although perceived error climate overlaps to some extent with classroom goal structure, it has been shown to have a distinct effect on students' learning (Steuer et al., 2013).

The Present Study

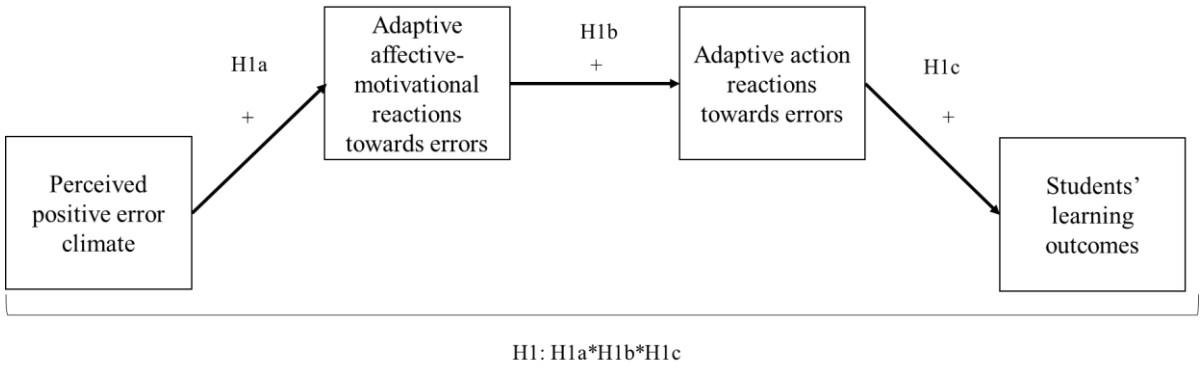
The present study aimed to expand the literature about the learning from errors model (Tulis et al., 2016). More precisely, to date, no research has tested the interplay between perceived error climate, the adaptive reactions towards errors and students' learning outcomes in a comprehensive model in which the contribution of personal variables (i.e., error beliefs) and other classroom variables (i.e., classroom goal structure) were controlled for. Indeed, although Tulis and colleagues' (2016) theoretical model includes all these constructs, no empirical research has so far included them in the same analysis: Grassinger and colleagues (2018) did test the association between perceived error climate, adaptive reactions towards errors and students' achievement, but their research neither included error beliefs—studied by Tulis and colleagues (2018) in conjunction with reactions towards errors—nor classroom goal structure—studied by Steuer and colleagues (2013) in conjunction with perceived error climate and adaptive reactions towards errors. Therefore, in the present study we analysed how perceived error climate is associated with students' mathematics grades via adaptive reactions towards errors, controlling for perceived classroom goal structure and error beliefs. In addition, since most of the studies that implemented this model have been carried out in the

German context, we provided further data on the generalizability of the model and on the validity and reliability of the related measures in another national educational context.

Accordingly, the present study had two main aims: (1) to test a comprehensive model that hypothesises that perceiving a positive error climate is related to students' learning outcomes in mathematics (i.e., mathematics grades), via adaptive reactions towards errors, while controlling for both error beliefs and classroom goal structure; and (2) to test for the first time the factorial structure and reliability of the error-related measures (i.e., error climate questionnaire, adaptive reactions towards errors and error beliefs scales) in a different context than Germany (i.e., Italy).

The following main hypothesis was formulated (Figure 1). We expected that perceived error climate would indirectly affect students' learning outcomes (i.e., grades in mathematics) via the two adaptive reactions towards errors (H1). More precisely, perception of a more positive error climate should be directly related to more adaptive affective-motivational reactions towards errors (H1a), which in turn, should be directly associated with more adaptive action reactions towards errors (H1b), which should result in higher students' learning outcomes (H1c), while the students' error beliefs and their classroom goal structure are controlled for.

Figure 1
Overview of the Hypotheses



Note. The black arrows refer to the hypothesized indirect effect of perceived classroom error climate on students' learning outcomes via affective-motivational reactions and action reactions towards errors (H1). This effect is the result of the three direct effects (i.e., H1a, H1b, H1c). Control variables are not represented in this Figure.

To test our hypotheses, we carried out a correlational study in Italian middle schools, and administered a questionnaire to students during mathematics classes, which have some interesting characteristics. First, errors in mathematics are generally more easily detectable than in other subjects because the answers expected in tests and exercises tend to be more univocal. Second, a peculiar feature of mathematics lessons in Italy is that students are often engaged in exercises in front of the class (i.e., exercises solved at the blackboard), and their errors are discussed publicly (Santagata, 2004). During this teaching practice, teachers' error handling strategies are implemented in front of all the students, thereby making their strategy highly salient. Third, according to the Italian middle school curricula (i.e., grade 6-8; Law 89/2009), mathematics is the subject with the second-highest number of teaching hours per week, after Italian. Students spend several hours in mathematics classes (between 6 to 9 hours), and mathematics is a core subject in the Italian school curriculum.

Method

Sample and Procedure

As simulation studies demonstrated that it is possible to obtain unbiased estimates in multilevel models even with samples including between 10 and 30 between-level units (i.e., classrooms; Huang, 2018; McNeish & Stapleton, 2016), we aimed at recruiting approximately 30 classrooms. A total of 563 students (M_{age} = 11.98, *SD* = 0.79, 54.2% girls, 4.7% with Specific Learning Disabilities certification) from 32 classes ($M_{\text{Students per class}}$ = 17.59) from three middle schools of one Italian region completed the questionnaire. Among these students, 4.1% were born in another country than Italy, and 15.8% spoke another language in addition to Italian. Nevertheless, all the students were able to understand the questionnaire and to complete it adequately, and thus, we did not exclude participants from the total sample.

The questionnaire comprised several self-report scales that referred to the mathematics class. As for the three error-related scales (i.e., perceived error climate, adaptive reactions

toward errors and error beliefs questionnaires, see Measures section), a forward-backward translation procedure had been performed. More precisely, a bilingual expert carried out the first translation from German to Italian. Then, another bilingual expert translated the Italian version back into German. Finally, the researchers and the two bilingual experts created the final translation, adjusting words and expressions to the Italian context.

Before data collection, we obtained the University Ethical Board's approval, the school headmasters' and teachers' agreement, and the parents' signed consent for each student. Data collection took place between December 2019 and February 2020 during mathematics classes. A trained researcher administered the questionnaire to the students who had from 30 to 45 minutes to complete it. After the first term of the school year (January 2020), mathematics teachers provided the summative mathematics grades obtained by the students, which were used as our dependent variable.

Measures

Perceived Error Climate. We used the Perceived error climate questionnaire developed and validated by Steuer and colleagues (2013). The scale comprises 31 items, divided into eight dimensions: Error tolerance by the teacher (e.g., "*In our math class errors are nothing bad for our teacher*", 4 items); Irrelevance of errors for assessment (e.g., "*If someone in our math class makes an error, he/she will get a bad grade*."-reverse coded, 4 items); Teacher support following errors (e.g., "*If someone in our math class can't solve an exercise correctly, the teacher will help him/her*", 4 items); Absence of negative teacher reactions to errors (e.g., "*If someone in our math class makes errors, the teacher often looks annoyed*"-reverse coded, 4 items); Absence of negative classmate reactions to errors (e.g., "*If someone in our math class solves an assignment incorrectly, his/her classmates will mock him/her*"-reverse coded, 4 items); Taking the error risk (e.g., *"In our math class a lot of students would rather say nothing at all than something that is wrong*."-reverse coded, 3

items); Analysis of errors (e.g., "*In our math class errors are investigated in detail.*", 4 items); Functionality of errors for learning (e.g., "*In our math class wrong answers on assignments are used to learn something*", 4 items). According to Steuer and colleagues (2013), the perceived error climate questionnaire is reliable as an eight-factor structure and a superordinate and uniform factor structure scale.

Adaptive reactions towards errors. Students' reactions following errors were measured with the two subscales of adaptive reactions towards errors developed and validated by Dresel and colleagues (2013). The scale consisted of 13 items divided into two dimensions: adaptive affective-motivational reactions (e.g., "*During a math class, if I say something incorrect, I still enjoy the class*", 6 items); and adaptive action reactions towards errors (e.g., "*When I can't do something in mathematics, then I try even harder the next time around*", 7 items).

Error beliefs. We used the 5-item scale developed by Tulis and colleagues (2018). The items focus on the importance of making errors for learning something new (e.g., "*I can learn something from my errors"*).

Classroom goal structure. The classroom goal structure was measured using the Pattern of Adaptive Learning Survey (Midgley et al., 2000). It comprised 14 items divided into three subdimensions: Mastery (e.g., "*In our math class, it is important to understand the subject well*", 6 items), performance-approach (e.g., "*In our math class, it is important to get good grades in tests*", 3 items), and performance-avoidance classroom goal structure (e.g., "*In our math class, it is important not to do worse than others*", 5 items).

Math grades. In the Italian education system, grades vary from 1 to 10, and 6 is the pass-fail cut-off grade. During the school year, students undergo two summative evaluations for each subject: the first, at the end of the first school semester (mid-September/end of January), and the second, at the end of the school year (June). These grades result from the

average of all the grades obtained by the students in various tests during the two semesters. In the present study, students' mathematics grades were provided by their teachers and refer to students' first semester summative grades (obtained in January 2020).

All the items were presented alongside a 5-point Likert scale, ranging from 1 ("*Not at all true*") to 5 ("*Totally true*"). The questionnaire also included demographic variables (i.e., sex and age), which were added as controls[9]. All items of the scales are reported in Table S1, both in the Italian and English versions.

Data Analysis

Although missing data were very few (1.15% in total, highest percentage in a single variable 2.66%), a significant Little's MCAR test suggested data were not missing completely at random, $\chi^2(928) = 11075.315$, $p < .001$. Therefore, since imputation is preferred to listwise deletion (Graham, 2009), missing data were imputed with the Expectation Maximization algorithm in SPSS Version.

Then, since the error-related scales (namely, perceived error climate, adaptive reactions towards errors and error beliefs) have not previously been translated and validated in Italian, we ran a series of confirmatory factor analyses (CFA) to test their factor structures. We also ran a CFA for the classroom goal structure to test if the two performance dimensions (i.e., performance-approach and performance-avoidance) are empirically distinguishable. CFAs were run with Mplus (version 6, Muthén & Muthén, 2007) using the TYPE = COMPLEX command to account for the nested structure of the data (i.e., students nested within classrooms). We set all the models using the Maximum Likelihood Robust chi-square estimator (MLR). We followed the cut-off criteria suggested by Bentler (1990) and Hu and

[9] In the questionnaire we also measured the personal achievement goals (Elliot & McGregor, 2008). However, in the current article we did not consider this variable because we focused on students' perceptions of classroom features (i.e., goal structure and error climate) related to teachers' attitudes, messages, and behaviours. Results including these variables are available upon request from the corresponding author.

Bentler (2009) to assess the models' fit. More precisely, Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) close to .95, Root Mean Square Error of Approximation (RMSEA) lower than .06 and Standardised Root-Mean Residual (SRMR) lower than .08 were taken into consideration. To compare models, we used the Satorra-Bentler scaled chi-square formula (Satorra & Bentler, 2010) and the conventional rule of thumb that the smaller the RMSEA and the larger the CFI, the better the fit.

Finally, we tested the hypothesized indirect effects (Figure 1) by running a two-level model, to adequately account for the variance components in the nested data (students in classrooms). Running a two-level model is recommended when the observations are not independent (i.e., students in the same classroom are likely to be more similar than students in different classrooms; see Hox et al., 2017). In this study, students represent the within-classroom level and classrooms represent the between-classroom level. At the within-classroom level, we estimated direct and indirect effects of perceived error climate (predictor) on students' learning outcomes (dependent variable) via the two affective-motivational and action reactions (mediators). We added to the model the two theoretically relevant control variables (error beliefs and classroom goal structure) and two demographic control variables (age and gender). At the between-classroom level, we regressed students' learning outcomes (dependent variable) and the adaptive reactions towards errors (mediators) on perceived error climate and classroom goal structure (contextual predictor and control). Therefore, perceived error climate and classroom goal structure, considered as students' perceptions of classroom characteristics, have been controlled at the within- and between-classroom levels as suggested by Lam and colleagues (2015) and Morin and colleagues (2014).

Results

Confirmatory Factor Analyses

Regarding the perceived classroom error climate, we tested three different models: the one-factor model (Model 1), the eight-factor model (Model 2), and the superordinate factor model (Model 3). Model 1 presented a poor fit with the data, whereas Model 3 and Model 2 have acceptable fit indexes (Table 1).

Table 1

Results from Confirmatory Factor Analyses of Error-Related Scales and Classroom Goal Structure Scale. Models' Fit Indices and Model Comparisons are Shown

Models	df or Δdf	χ^2 or $\Delta\chi^2$	RMSEA (C.I.)	CFI	TLI	SRMR	λ range
Perceived error climate							
Model 1 – one factor	434	2877.375	0.100 (0.097-0.103)	0.509	0.473	0.100	0.261-0.684
Model 2 – eight-factor	406	757.538	0.039 (0.035-0.044)	0.929	0.919	0.046	0.415-0.868
Model 3 – Superordinate	426	879.565	0.043 (0.039-0.048)	0.909	0.900	0.060	0.418-0.863
Model 1 vs Model 2	28	2629.053***					
Model 2 vs Model 3	20	-111.914					
Adaptive reactions towards errors							
Model 1 – one factor	54	511.298	0.123 (0.113-0.132)	0.759	0.705	0.097	0.258-0.762
Model 2 – two-factor	53	220.387	0.075 (0.065-0.085)	0.912	0.890	0.060	0.533-0.816
Model 1 vs Model 2	1	607.059***					
Error belief							
Model 1 – one factor	5	28.190	0.091 (0.060- 0.125)	0.969	0.939	0.028	0.697-0.843
Classroom goal structure							
Model 1 – two-factor	76	305.024	0.073 (0.065- 0.082)	0.890	0.869	0.061	0.408-0.697
Model 2 – three-factor	74	206.956	0.056 (0.047- 0.066)	0.936	0.922	0.054	0.406-0.784
Model 1 vs Model 2	2	707.386***					

Note. *** $p < .001$

As for the Adaptive reaction towards errors scale, we tested the two-factor structure of the 13-item scales, and the results showed a poor fit with the data, $\chi^2(64) = 359.052$, $p < .001$, RMSEA = 0.090, 90% C.I. RMSEA = 0.081- 0.100, CFI = 0.869, TLI = 0.840, SRMR = 0.076). Modification indices highlighted that one item of the affective-motivational subscale resulted in higher loadings on the action reactions subscale, and by deleting it, the χ^2 decreased. One possible explanation is that the wording of the item may have been ambiguous (i.e., "*In mathematics when I don't know how to do something, I still want to work*"), and thus,

students may have referred to an action (working) made after erring (i.e., action reactions) rather than to the motivation or affect regulation (i.e., affective-motivational reactions). Therefore, we removed this item from subsequent analyses, and we compared the two-factor structure with 12 items (Model 2) with the one-factor structure with 12 items (Model 1). Results revealed that Model 2 had a better fit than Model 1.

Finally, we tested the unifactorial structure of the error beliefs scale, which fitted the data well, and we compared two models for the classroom goal structure: A two-factor model in which one factor represented the merged performance classroom structures (approach and avoidance) and the other factor represented the mastery structure (Model 1), and a three-factor model in which the items loaded on the three subscales (Model 2). Model 2 fitted the data better than Model 1.

Descriptive Statistics

We created composite scores for each variable, by averaging answers to the respective items. As reported in Table 2, Cronbach's alphas showed satisfactory reliability for all measures and all the variables are associated in the expected direction at the bivariate level. For an easier comparison, descriptive statistics and reliability of the German and Italian scales are provided in the Supplementary Online Materials (Table S2).

Table 2

Descriptive Statistics, Bivariate Correlations, Intraclass Correlation (ICCs) and Internal Consistency (Cronbach' s alpha) of All Variables

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1.Perceived classroom error climate Uniform factor	-	.584**	.657***	.759**	.747***	.530***	.398***	.652***	.543***	.557***	.443***	.450***	.435***	-.294**	-.183**	.206*
2.Error tolerance by the teacher		-	.345**	.370**	.376**	.144**	.064	.263**	.264**	.237**	.210**	.176**	.187**	-.161**	-.189**	.082
3.Irrelevance of errors for assessment			-	.457**	.498**	.286**	.167**	.294**	.200**	.383**	.224**	.190**	.229**	-.260**	-.183**	.115**
4.Teachers support following errors				-	.520**	.258**	.172**	.535**	.382**	.426**	.382**	.372**	.389**	-.169**	-0.91*	.144**
5.Absence of negative teachers' reactions					-	.398**	.303**	.341**	.246**	.477**	.246**	.256**	.263**	-.235**	-.148**	.168**
6.Absence of negative classmate reactions						-	.195**	.156**	.152**	.290**	.144**	.179**	.181**	-.284**	-.069	.161**
7.Taking the error risk							-	.139**	-.055	.321**	.078	.033	.011	-.041	.013	.066
8.Analysis of errors								-	.399**	.358**	.467**	.375**	.411**	-.137**	-.057	.115**
9.Functionality of errors for assessment									-	.234**	.382**	.578**	.423**	-.150**	-.165**	.150**
10.Affective-motivation reactions towards errors										-	.452**	.308**	.292**	-.238**	-.110**	.289**
11.Action reactions towards errors											-	.500**	.612**	-.072	-.011	.256**
12.Error beliefs												-	.511**	-.111**	-.131**	.122**
13.Mastery CGS													-	-.007	.073	.145**
14.Performance-avoidance CGS														-	.610**	-.207**
15.Performance-approach CGS															-	-.161**
16.Math grades																-
M	3.680	2.957	4.075	4.118	4.101	4.138	2.475	3.602	3.674	3.536	3.787	3.972	4.279	2.690	3.433	6.961
(*SD*)	(0.495)	(0.818)	(0.746)	(0.791)	(0.744)	(0.803)	(1.020)	(0.838)	(0.828)	(0.831)	(0.763)	(0.758)	(0.614)	(0.888)	(0.958)	(1.262)
α	.880	.591	.740	.781	.744	.862	.804	.783	.723	.788	.865	.859	.771	.759	.782	-

Note. * $p < .05$, ** $p < .01$

Two-Level Path Analysis

The analysis of the intraclass correlations (ICC, Table 2) showed that mathematics grades significantly varied across the classrooms, as did the affective-motivational reactions towards errors. The action reactions towards errors had a nearly significant between-classroom level variance (p = .06) and the ICC was higher than .05. Therefore, data analysis was run with a two-level approach, including classroom-level predictors of adaptive reactions towards errors and mathematics grades[10].

In the path analysis we tested the hypothesized indirect effect of perceived classroom error climate on students' mathematics grades via the two adaptive reactions towards errors (i.e., affective-motivational and actions reactions towards errors), controlling for students' error beliefs and classroom goal structure. To reduce the complexity of the model, we used only the single composite score of perceived error climate as within-level and between-classroom level predictor[11], since the superordinate factor structures fitted well the data. We used Maximum Likelihood Robust (MLR) as estimation method. We controlled for error beliefs, age, and gender only at the within-classroom level and for classroom goal structures both at the within and at the between-classroom level.

The findings of the two-level path model are presented in Figure 2 and in Table 3. Supporting our main hypothesis (H1), the sequential indirect effect of the perceived classroom error climate on students' learning outcomes via both adaptive reactions towards errors was significant, b = 0.05, $S.E.$ = 0.02, p = .002. Thus, perceiving positive classroom error climate was related to more adaptive affective-motivational reactions towards errors

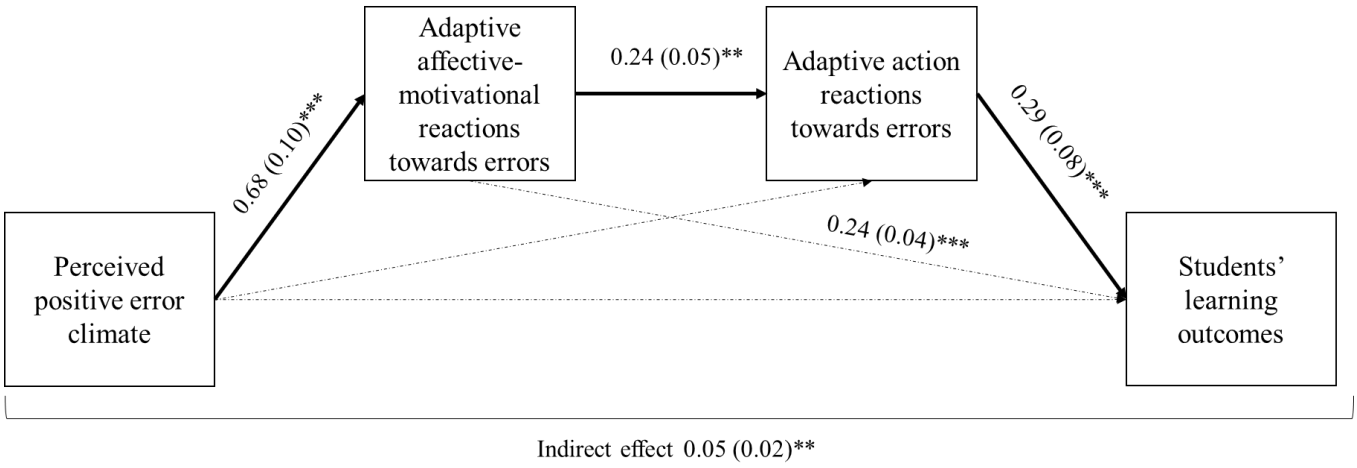
[10] To explore if our model's random slopes variances were significant, we tested the random slopes for each of the main relations. Findings suggested that associations between perceived error climate, adaptive reactions towards errors, d students' grades did not significantly vary across classrooms (ps > .9 see Table S3 in the Supplementary Online Materials).

[11] We also ran the path analysis with the eight error climate dimensions as within-level predictors and the single composite score as between-level predictor, but the program could not compute the analysis (because of the complexity of the model). Nevertheless, we provided in the Supplementary Online Materials (Table S4) the results of a within-subject path analysis, in which we entered the eight subdimensions as predictors.

(H1a), which, in turn, was related to more adaptive action reaction towards errors (H1b), which was related to high students' learning outcome (H1c). Differently from our expectation, we also found a significant direct path between affective-motivational reactions and students' learning outcomes, and a significant indirect effect of perceived error climate on students' learning outcomes via affective-motivational reactions (b = 0.17, *S.E.* = 0.06, p = .002, Figure 2). At the between-level, we found a positive relationship between perceived classroom error climate and affective-motivational reactions, and between perceived classroom error climate and learning outcomes (Table 3).

Figure 2

Two-Level Path Model Results. Significant Unstandardized Results at the Within-Level Are Shown. Standard Errors are Presented in Brackets



Note. The indirect effect at the bottom of the figure represents the indirect effect of perceived error climate on students' learning outcomes (H1). The dashed arrows represent the estimated paths which were not part of the hypothesized model. Only a significant estimated of these estimates path is shown. For the sake of clarity, the results regarding the control variables are only reported in Table 3. ** p < .01, *** p < .001.

In addition to our hypothesized model, we also found a significant direct effect of affective-motivational reactions on students' learning outcomes and a significant simple indirect effect of perceived error climate on students' learning outcomes via affective-motivational reactions (b = 0.17, *S.E.* = 0.06, p = .002).

As for the classroom goal structure, at the within-classroom level mastery classroom goal structure was associated with higher adaptive action reactions towards errors, whereas performance-avoidance classroom goal structure was negatively associated with affective-

motivational reactions and students' learning outcomes (Table 3). On the contrary, no significant relation was found at the between-classroom level. Further, we found a positive association between error beliefs and adaptive action reactions to errors, and a negative relation between gender and affective-motivational reactions, indicating that boys reacted more adaptively to errors than girls.

Table 3

Two-Level Path Model Unstandardized Results at the Within and Between Level. Standard Errors are Shown in the Brackets

	Affective-motivational reactions towards errors	Adaptive action reactions towards errors	Students' learning outcomes (mathematics grades)
	b (S.E.)	b (S.E.)	b (S.E)
Within-level predictors			
Perceived error climate	0.680 (0.097)***	0.057 (0.081)	- 0.134 (0.161)
Affective-motivational reactions towards errors	-	0.239 (0.052)***	0.243 (0.087)**
Action reactions towards errors	-	-	0.291 (0.082)***
Error beliefs	0.095 (0.056)	0.191 (0.061)**	- 0.019 (0.081)
Mastery CGS	0.083 (0.083)	0.499 (0.043)***	0.005 (0.132)
Performance-avoidance CGS	- 0.144 (0.038)***	0.025 (0.048)	- 0.194 (0.082)*
Performance-approach CGS	0.033 (0.041)	0.006 (0.038)	- 0.093 (0.070)
Age	0.006 (0.064)	- 0.049 (0.067)	0.030 (0.081)
Gender (1 = Male, 2 = Female)	- 0.231 (0.061)***	0.051 (0.074)	0.006 (0.109)
Between-level predictors			
Perceived error climate	1.326 (0.335)***	0.213 (0.240)	0.984 (0.388)*
Mastery CGS	0.218 (0.896)	1.054 (0.690)	3.215 (1.826)
Performance-avoidance CGS	0.363 (0.894)	0.046 (0.537)	3.256 (1.775)
Performance-approach CGS	0.100 (1.247)	0.011 (0.849)	- 3.343 (2.430)
R^2_{within}	0.283 (0.039)	0.462 (0.032)	0.111 (0.022)
R^2_{between}	0.969 (0.402)	0.975 (1.179)	0.890 (0.657)

Note: *$p < .05$; **$p < .01$; ***$p < .001$

Discussion

This study was set out to advance the existing knowledge on the learning from errors model (Tulis et al., 2016) in different ways. We tested the indirect relations between perceived error climate and students' learning outcomes via adaptive reactions towards errors in a comprehensive multi-level model which included other variables, namely students' error beliefs and classroom goal structure. Moreover, we generalised existing evidence (e.g., Dresel et al., 2013; Steuer et al., 2013; Tulis et al., 2018) to another context than the German one, by administering error-related scales to Italian middle school students for the first time.

The first contribution pertains to our main hypothesis that perceived error climate is indirectly associated with students' learning outcomes via two adaptive reactions towards errors (i.e., affective-motivational and action reactions), while controlling for error beliefs and classroom goal structure. Differently from previous research (i.e., Grassinger et al., 2018; Steuer et al., 2013; Tulis et al., 2018) that tested the associations between parts of the model, we provided empirical evidence for a comprehensive model that allows understanding the psychological and classroom dynamics related to the learning from errors process.

In addition to the hypothesized indirect effect, the affective-motivational reactions towards errors were also directly related to students' learning outcomes, underling the central role of emotional and motivational regulations in determining the learning-from-errors process (Tulis et al., 2016) and the actual learning. Broadening the focus, these results are in line with other findings based on self-regulated learning theories (Heemsoth & Heinze, 2016; Ramdass & Zimmerman, 2008), which pointed out the role of emotional, motivational, and cognitive strategies in supporting learning from errors.

The association between error beliefs and action reactions is partially in line with Tulis and colleagues (2018) who found a small association also with affective-motivational reactions. As explained by the authors, it is plausible that believing that errors are useful for

learning may push students to activate cognitive responses (such as deeply analysing the error).

As for classroom goal structures, students' perception of mastery structure was positively associated with action reactions towards errors, whereas students' perception of performance-avoidance classroom structure was negatively related to affective-motivational reactions towards errors and students' mathematics grades. These results are in line with previous literature (see Meece et al., 2006; Givens Rolland, 2012), supporting that mastery teaching orientations promote students' motivation and learning outcomes.

An additional methodological conclusion of this study stems from the two-level structure of the analyses. At the between-classroom level, we found a positive relationship between perceived classroom error climate and affective-motivational reactions towards errors and learning outcomes. Therefore, in addition to individual differences in the perception of error climate, students in classrooms with a higher perception of a positive error climate had more adaptive affective-motivational reactions towards errors and better math grades. The first result corroborated the findings of Steuer and colleagues (2013), supporting the idea that shared perception of the error climate (i.e., perception of error climate at the classroom-level) is related to the personal affective-motivational reactions. The second result adds to Steuer and colleagues' results, which showed that perceived error climate at the classroom-level was related to students' efforts' regulation.

The second contribution of the present research relies on the analysis of the factor structure and the internal consistency of the error-related scales. We confirmed that the perceived error climate questionnaire, the adaptive reactions towards errors scale, and the error belief scale are reliable and valid instruments to measure error-related perception, reactions, and beliefs in Italian middle school context. In line with previous results (Steuer et al., 2013; Dresel et al., 2013; Tulis et al., 2018) our findings confirmed both the eight-factor

and the superordinate factor structures of the perceived error climate questionnaire, the two-factor structure with 12 items of the adaptive reactions towards errors scale, and the one-factor structure of the error beliefs scale. Furthermore, correlations between the error-related variables were in the expected direction (i.e., positive) and medium-high, suggesting convergent validity. The fact that these results replicated in two different countries (Germany and Italy, see Table S2) supports for the first time the external validity of both the model and the instruments, as far as generalization to different national contexts is concerned.

In addition, we provided insights on Italian middle school students' error beliefs, perceptions of error climate and reactions towards errors for the first time. Our results corroborated previous findings (Steuer et al., 2013; Tulis et al., 2018), showing that participants on average perceived an overall positive error climate, held positive beliefs about errors and reacted adaptively after erring. Although a systematic intercultural comparison is beyond the scope of the present study, it should be noted that other research carried out in different countries with different measures reported similar findings. Pan and colleagues (2020) found that Canadian and US students believed that making errors is part of the learning process and something positive for learning. They endorsed the value of error correction, but only a minority among them expressed motivation to try harder after erring. Kyaruzi and colleagues (2020) reported that Tanzanian students tended to use errors fruitfully for their learning and perceived their teachers as supportive after erring.

Furthermore, our results support prior findings on teachers' error-related practices. Indeed, the perceived error climate dimensions are largely related to teachers' attitudes (the first four dimensions) and management of classmates' reactions and errors (the other four dimensions). Students' high rating of teachers' positive affective responses, supportive behaviours, and error-based teaching methods (e.g., analysis of errors dimension) are related to students' better achievement, lower fear of making errors and more positive perceptions of

the classroom climate (see, Heinze et al., 2012; Kyaruzi et al., 2020; Rach et al., 2013; Tulis, 2013). Overall, although cultural differences in teachers' error handling practices may exist (Santagata, 2005; Stigler & Hiebert, 1999), these findings corroborated the idea that teachers have a pivotal role in determining how students react to errors and use them effectively for learning.

Limitations and Further Research

The present study has some limitations. First, although the hypothesized and found sequential indirect effect is theoretically grounded in relevant literature, data were correlational, and thus causality could not be firmly established. Future research should aim at extending and replicating our findings with longitudinal and experimental designs.

Second, the use of self-report measurements, through which we measured the predictor and the mediators, may lead to common method bias. Although our dependent variable derived from a different source (students' grades obtained from teachers) than the independent ones (Podsakoff et al., 2003), future research could include observational techniques to assess students' perceptions or teachers' behaviours (see Santagata, 2005; Tulis, 2013). Furthermore, given our use of self-reported questionnaires to assess students' perceptions of errors, we could not know the error situation students were thinking about (e.g., making errors at the blackboard, or during homework correction). Future research could limit this ambiguity by using realistic vignettes (see Bauer, 2008) or interviewing students (as in Santagata, 2004).

Another limitation of this study concerns the focus on specific variables (e.g., classroom goal structure), a specific domain (i.e., mathematics) and school level (i.e., middle school). Indeed, we did not consider other aspects of the classroom—such as the assessment method (i.e., formative vs normative)—or the characteristics of the students—such as their previous mathematics knowledge—that may affect the perceptions of error climate and their

adaptive reactions towards errors. Furthermore, students' perceptions of error climate, error beliefs and reactions may change in different domains, as highlighted by Tulis and colleagues (2018), or throughout the school levels, as happens for other students' features (e.g., mastery goal, interest and academic self-concept, Yeung et al., 2011; Liu & Wang, 2005). Future research could therefore explore which other variables (e.g., the relevance of formative assessment in class, previous knowledge) may affect students' perceptions of error climate and their reactions towards errors, and if these variables differ among school domains and levels.

Finally, our dependent variable, namely students' mathematics grades, cannot be considered a full indicator of students' learning, but only one parameter to assess students' learning process. Grades result from a complex interplay between several factors (e.g., Authors, 2008), which includes students-related variables (e.g., their motivation, commitment, and cognitive resources) and teachers-related variables (e.g., their knowledge about students' characteristics, Dompnier et al., 2006). Therefore, the definition of grades as learning outcomes may reduce the complexity of both the processes involved in scholastic judgments and learning. Further research should assess other variables related to the learning process, such as acquisition of new knowledge, besides learning outcomes expressed in grades.

Practical Implications

Our findings suggest that students' perceptions of a positive error climate help them to positively adjust to errors and improve their learning outcomes. Establishing a positive error climate depends on how teachers' handle student' errors during the lessons (Authors, 2020). Therefore, in line with previous research on teacher training (e.g., Heemsoth & Heinze, 2016; Kyaruzi et al., 2020), our findings might be used to develop training to make teachers aware of the importance of establishing a positive error climate to improve students' self-regulated processes (i.e., adaptive reactions towards errors) and learning.

Conclusion

The present study contributes to enrich the line of research on the learning from errors model (Tulis et al., 2016) by highlighting that students' perceptions of the error climate is a key variable strictly intertwined with their reactions towards errors and, in turn, with learning outcomes. Broadening the focus further, this study also echoes all the research findings that underline the importance of establishing an error friendly environment (e.g., Kafer et la., 2019; Steuer et al., 2013; Spychiger et al., 2006) and, more generally, a supportive classroom environment to promote students' emotions, motivations, and learning process (e.g., Gasser et al., 2018; Frenzel et al., 2007; Wang et al., 2020).

Supplementary Materials

Error-related Questionnaires – Italian Translation

In Table S1, items of the three error-related scales (i.e., perceived error climate questionnaire, Adaptive reactions towards errors scale and Error beliefs scale) are shown. We provided the English version, retrieved from the literature, and the Italian version, administered to the students of this study.

Table S1

Items of the Three Error-Related Scales. English and Italian Version Are Provided

English version	Italian version
Perceived error climate questionnaire - Steuer and colleagues (2013)	
Error tolerance by the teacher	
In our Math class it is okay with our teacher if the assignments are not done correctly	Per l'insegnante, se gli esercizi non sono eseguiti correttamente, non è un problema.
In our Math class mistakes are nothing bad for our teacher	Per l'insegnante, gli errori non sono da considerarsi qualcosa di negativo
In our Math class our teacher doesn't like if something is done incorrectly.	Per l'insegnante, non è un problema se qualcuno dice qualcosa di errato.
In our Math class it is not at all bad for our teacher if someone says something incorrect	All'insegnante non piace se qualcosa viene svolto in maniera errata.
Irrelevance of errors for assessment	
If someone in our Math class makes a mistake, he will get a bad grade	Se qualcuno commette un errore, prende un brutto voto.
If someone in our Math class says something wrong, it has an immediate effect on his grade	Se qualcuno sbaglia qualcosa, prende un brutto voto.
If someone in our Math class does something incorrectly, he will get a bad grade	Se qualcuno dice qualcosa di errato, questo ha un effetto immediato sulla sua valutazione.
If someone in our Math class does not do his assignment correctly, he will immediately get a bad grade	Se qualcuno non svolge correttamente i suoi compiti, prenderà subito un brutto voto.
Teacher support following errors	
If someone in our Math class can't solve an exercise correctly, the teacher will help him.	Se qualcuno non sa risolvere un esercizio correttamente, l'insegnante lo aiuta.
If someone in our Math class does something wrong, he will get support from the teacher.	Se qualcuno sbaglia, viene aiutato dall'insegnante.
If someone in our Math class says something incorrect, the teacher will patiently explain the problem	Se qualcuno dice qualcosa di scorretto, l'insegnante gli spiega pazientemente il problema.
If someone in our Math class does something wrong, he will get very little support from the teacher.	Se qualcuno sbaglia qualcosa, riceve poco aiuto da parte dell'insegnante.
Absence of negative teacher reactions to errors	

If someone in our Math class does something incorrectly, he might be mocked by the teacher	Se qualcuno sbaglia, può succedere che l'insegnante lo derida.
If someone in our Math class solves an assignment incorrectly, once in a while the teacher will become angry.	Se qualcuno risolve un esercizio in modo errato, a volte l'insegnante si arrabbia.
If someone in our Math class says something wrong, sometimes the teacher will embarrass him in front of the entire class.	Se qualcuno dice qualcosa di errato, a volte l'insegnante lo mette in imbarazzo di fronte a tutta la classe.
If someone in our Math class makes mistakes, the teacher often looks annoyed	Se qualcuno commette degli errori, l'insegnante spesso sembra infastidito.

Absence of negative classmate reactions to errors

If someone in our Math class does something wrong, he will sometimes be ridiculed by his classmates	Se qualcuno sbaglia a risolvere un esercizio, i suoi compagni lo deridono.
If someone in our Math class says something incorrect, he will later have to put up with teasing from his classmates	Se qualcuno commette un errore in classe, può succedere che venga preso in giro dai compagni.
If someone in our Math class makes mistakes, his classmates will sometimes make fun of him	Se qualcuno durante la lezione di matematica commette degli errori, qualche volta i compagni lo prendono in giro.
If someone in our Math class solves an assignment incorrectly, his classmates will mock him.	Se qualcuno durante la lezione dice qualcosa di scorretto, dopo dovrà sopportare le prese in giro dei suoi compagni.

Taking the error risk

In our Math class a lot of students don't dare to say anything because they are afraid it is wrong	Molti studenti non osano dire nulla perché hanno paura di sbagliare.
In our Math class a lot of students hope they will not be called on, because they are afraid they will say something wrong.	Molti studenti sperano di non essere chiamati, perché hanno paura di dire qualcosa di sbagliato.
In our Math class a lot of students would rather say nothing at all than something that is wrong	Molti studenti preferiscono non dire nulla piuttosto che dire qualcosa di sbagliato.

Analysis of errors

In our Math class we discuss it in detail when something is done incorrectly	Si discute in modo approfondito se qualcosa viene svolto in maniera scorretta.
In our Math class assignments that are done incorrectly are discussed in detail	Gli esercizi svolti in maniera errata vengono discussi in dettaglio.
In our Math class we think about it in detail when someone says something wrong	Quando qualcuno dice qualcosa di sbagliato ne parliamo insieme in modo approfondito.
In our Math class mistakes are investigated in detail	Gli errori sono analizzati in modo approfondito.

Functionality of errors for learning

In our Math class wrong answers are often a good opportunity to really understand the material	Le risposte sbagliate sono spesso una buona opportunità per comprendere i contenuti.
In our Math class we learn a lot from assignments that were not done correctly	Impariamo molto dai compiti che non sono stati svolti correttamente.
In our Math class the mistakes students make are often used to make sure you really understand Math	Gli errori commessi dagli studenti sono utilizzati spesso per capire meglio la materia.
In our Math class wrong answers on assignments are used to learn something	Le risposte sbagliate sono utilizzate per imparare qualcosa.

Adaptive reactions from errors scale – Dresel and colleagues (2013), retrieved from Tulis and colleagues (2018)	
Affective-motivational reactions towards errors	
	In matematica quando io…
When I say something wrong in mathematics, then the class is ruined as far as I am concerned.	Dico qualcosa di sbagliato, questo mi rovina tutta la lezione
When I say something wrong in mathematics the class is still just as fun for me as always	Dico qualcosa di sbagliato, la lezione mi piace comunque.
When I can't do something in mathematics, the lessons in the future will still be just as fun for me as always.	Non so fare qualcosa, la lezione continuerà a piacermi.
When I can't solve a math problem, then I have less motivation next time around.	Non riesco a risolvere un esercizio, la volta dopo ho meno voglia di fare matematica
When I make an error in mathematics, then I will have less fun in math/ class later on.	Faccio un errore la lezione di matematica mi piace meno.
Action-reaction towards errors	
	In matematica quando io…
When I can't do something in mathematics, then I try even harder the next time around.	Non so fare qualcosa, la volta seguente mi impegno ancora di più.
When something is too hard for me in mathematics, then it's clear that I need to prepare better for class	Non so fare qualcosa, mi rendo conto che mi devo preparare più.
When I make an error in mathematics, then I set a goal to try to improve myself.	Faccio un errore, cerco di migliorarmi in particolare su ciò che ho sbagliato.
When I make a mistake in mathematics, then I know where I will have to focus my efforts next time around.	Faccio un errore, so in cosa devo impegnarmi di più la prossima volta.
When I do something wrong in mathematics, then I specifically try to work it out.	Faccio qualcosa di sbagliato cerco di recuperare studiando quello che non so.
When I am not able to solve a math problem, this helps me to know where I can improve myself	Non riesco a fare un esercizio, questo mi aiuta a capire dove posso migliorare.
When I can't solve a math problem, then I practice these types of exercises on my own.	Non riesco a fare un esercizio, mi esercito proprio su quel tipo di esercizio.
Error Beliefs – Tulis and colleagues (2018)	
	In matematica…
I can learn something from my errors in mathematics	Posso imparare qualcosa dai miei errori.
Errors are important for getting better at mathematics	Gli errori sono importanti per migliorare.
I develop new skills by making errors in mathematics	Commettendo errori sviluppo nuove capacità.
My errors help me to improve my skills in mathematics	Gli errori mi aiutano a migliorare le mie capacità.
Errors in mathematics help me to be better later on	Gli errori mi aiutano a migliorare anche in seguito.

Table S2

Descriptive Statistics and Cronbach's Alpha of Italian and German Versions of the Error-related Scales (e.g., Perceived classroom error climate, Adaptive reactions to errors scale, Error beliefs scale)

	Italian questionnaire		German questionnaire	
	M (*SD*)	α	*M* (*SD*)	α
Perceived classroom error climate subdimensions (Uniform factor) [a]	3.61 (0.49)	.88	4.26 (0.65)	.76
Error tolerance by the teacher	2.96 (0.81)	.60	4.23 (1.00)	.72
Irrelevance of errors for assessment	4.07 (0.74)	.74	4.75 (0.77)	.70
Teachers support following errors	4.11 (0.79)	.78	4.72 (1.03)	.81
Absence of negative teachers' reactions	4.10 (0.80)	.74	4.75 (1.14)	.82
Absence of negative classmate reactions	4.14 (0.80)	.86	4.09 (1.20)	.86
Taking the error risk	2.47 (0.83)	.81	3.22 (1.25)	.81
Analysis of errors	3.61 (0.83)	.78	4.13 (1.01)	.80
Functionality of errors for assessment	3.67 (0.83)	.73	4.15 (1.09)	.80
Affective-motivation reactions towards errors [a]	3.53 (0.82)	.79	4.16 (0.98)	.83
Action reactions towards errors [a]	3.78 (0.76)	.87	4.37 (0.92)	.91
Error beliefs [b]	3.96 (0.76)	.86	4.21 (1.11)	.90

Note. [a] Descriptive statistics retrieved from Steuer et al. (2013), [b] Descriptive statistics retrieved from Tulis et al. (2018), 6-point Likert scales were used in Steuer et al.'s (2013) and Tulis et al.'s (2018) studies.

Preliminary analyses – random slopes model

In order to control if the associations between the main predictor of the model (perceived error climate), the mediators (adaptive reactions towards errors), and the dependent variable (students' learning outcomes) vary between classrooms, we estimate the random slopes for each association. Results are shown in Table S2. Since random slope variances were not significant, we tested a random intercept model (see main text, Data Analysis and Results sections).

Table S3
Results of Random Slopes Estimation. Random Slopes' Means, Variance and P-value of Variance Are Reported

	Affective-motivational reactions towards errors			Action reactions towards errors			Students' learning outcomes (mathematics grades)		
	Random slope mean (*S.E.*)	Random slope variance (S.*E.*)	*p* variance	Random slope mean (*S.E.*)	Random slope varinace (*S.E.*)	*p* variance	Random slope mean (*S.E.*)	Random slope varinace (*S.E.*)	*p* variance
Perceived error climate	6.780 (0.965)	0.001 (0.429)	0.998	4.245 (1.007)	0.001 (0.248)	0.998	0.401 (0.105)	0.001 (0.016)	0.949
Affective-motivational reactions towards errors	-	-	-	0.399 (0.037)	0.001 (0.002)	0.912	0.375 (0.055)	0.001 (0.010)	0.975
Action reactions towards errors	-	-	-	-	-	-	0.359 (0.054)	0.001	0.970

Table S4

Unstandardized Parameters from the Path Model Linking the Eight Subdimensions of Perceived Error Climate and the Other Variables

	Affective-motivational reactions towards errors	Adaptive action reactions towards errors	Students' learning outcomes (math grades)
	b (*S.E.*)	*b* (*S.E.*)	*b* (*S.E*)
	Direct effects		
Perceived error climate subdimensions			
Error tolerance by the teacher	0.020 (0.037)	0.026 (0.023)	-0.050 (0.061)
Irrelevance of errors for assessment	0.105 (0.049)*	-0.004 (0.032)	-0.073 (0.090)
Teachers support following errors	0.113 (0.052)*	0.007 (0.034)	0.002 (0.089)
Absence of negative teachers' reactions	0.224 (0.064)***	-0.093 (0.041)*	0.040 (0.089)
Absence of negative classmate reactions	0.024 (0.040)	-0.028 (0.039)	0.101 (0.070)
Taking the error risk	0.151 (0.030)***	-0.013 (0.028)	-0.013 (0.062)
Analysis of errors	0.070 (0.056)	0.154 (0.040)***	-0.095 (0.075)
Functionality of errors for assessment	-0.022 (0.044)	-0.003 (0.035)	0.104 (0.079)
Affective-motivational reactions towards errors	-	0.258 (0.041)***	0.297 (0.090)**
Action reactions towards errors	-	-	0.335 (0.084) ***
Error beliefs	0.135 (0.056)*	0.170 (0.045)***	-0.144 (0.095)
Age	-0.004 (0.039)	-0.048 (0.021)*	-0.029 (0.081)
Gender (1 = Male, 2 = Female)	-0.209 (0.059)***	0.069 (0.049)	0.021 (0.120)
Mastery CGS	0.119 (0.082)	0.485 (0.042)***	0.016 (0.129)
Performance-avoidance CGS	-0.135 (0.034)***	0.008 (0.052)	-0.130 (0.078)
Performance-approach CGS	0.025 (0.039)	0.013 (0.041)	-0.119 (0.062)
R^2	0.378 (0.041)	0.515 (0.042)	0.142 (0.026)
	Indirect effects		
Irrelevance of errors for assessment via affective-motivational reactions	-	0.027 (0.013)*	-
Teacher support following errors via affective-motivational reactions	-	0.029 (0.013)*	-
Absence of negative teachers' reactions via affective-motivational reactions	-	0.058 (0.019)**	-
Taking the error risk via affective-motivational reactions	-	0.039 (0.010)***	-
Absence of negative teacher reactions via affective-motivational reactions and action reactions	-	-	0.019 (0.007)**
Taking the error risk via affective-motivational reactions and action reactions	-	-	0.013 (0.004)**

Note. Standard errors are shown in brackets. Estimator used was Maximum Likelihood Robust and analysis was ran using the TYPE = COMPLEX procedure in Mplus, considering the classes (N = 32) as the cluster. Significant indirect effects only are reported. *p < .05, **p <.01, ***p <.001

Chapter 9

General discussion

1. Highlights of the empirical studies

The main aim of this dissertation was to analyse the role of errors in the learning process through three different levels of analysis (Mercer & Littleton, 2007): Psychological, relational, and cultural (Chapter 1). After describing the relevant literature related to the learning from errors process and the relational and cultural variables that affect it (Chapter 2 – 3 – 4), in the empirical part (Chapters 6 – 7 – 8), three different studies were presented. Although conceived as separate, if analysed together, these studies provide a rich overview of the different mechanisms and variables that support the learning from errors process.

In this section, we summarise the contributions of the three studies separately. Then we discuss the general contributions considering the findings together. Finally, after presenting the limitations of this dissertation, we provide suggestions for practical applications of the results.

1.1. Cultural level: Three errors meanings and the role of normative grading

As stated in Chapter 1, the cultural level of analysis encompasses cultural values, norms, and meanings shared in society and conveyed through social institutions, such as the education system (Mercer & Littleton, 2007). In this respect, we considered how teachers' practices are linked with their beliefs, which are culturally determined (Brown, 2004; Thompson, 1992), and change according to structural characteristics of education systems (i.e., normative grading assessment). Study 1 (Chapter 6) explored teachers' beliefs and practices related to students' mistakes and the negative interdependence between errors and evaluation. The qualitative approach allowed a deep investigation into how teachers consider students' errors, describing their error-related practices and interpreting the relationship between errors and normative grading. Through the reflexive thematic analysis (Braun &

Clarke, 2006; 2020), seven themes emerged from the data, reflecting teachers' beliefs and teachers' practices. The findings of this study can be summarised in three points. First, teachers of the sample believed that errors have different roles and characteristics related to three meanings (i.e., pedagogical, sanctioning, and threatening). Second, these different meanings were associated with specific teachers' error-handling practices aimed at including errors in the activities, penalising errors, or emphasising their positive role, respectively. Third, teachers acknowledged the negative interdependence between errors and evaluation (i.e., the more errors, the lower the grade). This negative interdependence turned out to have two main consequences. On the one hand, teachers admitted that presenting errors positively while assessing students with grades is challenging, and they must find specific strategies to face this challenge. On the other hand, teachers said that grades are used to penalise errors to educate students (i.e., to punish a lack of commitment or humility).

The first contribution of study 1 was to enrich the literature on teachers' beliefs about errors and their relationship with practices. In line with previous research (e.g., Bray, 2011; Schleppenbach et al., 2007), our results showed that teachers hold different beliefs about the errors in the learning process. These beliefs are linked to different meanings and lead teachers to adopt specific error-handling practices. This first contribution expanded the literature about teachers' beliefs, providing a more detailed description of the error-related beliefs teachers hold. Indeed, errors are not perceived as only "bad" or "good" by teachers (Schleppenbach et al., 2007, p. 140) but useful (pedagogical meaning) or detrimental to learning (sanctioning meaning) or harmful to students (threatening meaning). Moreover, the main distinction between the pedagogical and sanctioning meanings seemed to be based on attributing responsibility for the error to the student.

As for the association with practices, this study's findings may be interpreted in light of the idea that teachers' beliefs frame situations and guide teachers' intentions and actions

(Fives & Buehl, 2011). Even though we did not directly observe actual practices adopted by teachers, participants provided examples of error-handling strategies they generally used during school activities. For instance, if teachers recognised a pedagogical meaning to errors, they reported adopting error-handling strategies to support the student in elaborating them. On the contrary, if teachers attributed a sanctioning meaning to errors because they ascribed the responsibility of a certain mistake to the student, teachers used strategies to penalise the error. Therefore, it is possible to argue that beliefs about errors help teachers interpret the situation in which errors occur and guide their subsequent practices.

As for the negative interdependence between errors and grades, our findings align with the idea of the double role of education systems (e.g., Darnon et al., 2009) reflected on teachers (Batruch et al., 2019; Butera et al., 2021). As shown in Chapter 4, normative grading is related to the selective function of education systems, with the aim to divide and select students based on their performance. Differently, the educational function aims at providing students with knowledge and skills, and it is reflected in the formative assessment practices (Darnon et al., 2009). To fulfil these two functions, teachers play both educator and gatekeeper roles: The first role is in line with the educational function of education systems, and the second role with the selective one. As a result, when teachers recognized the pedagogical meaning of errors, they saw normative grading as an impediment to presenting and using errors as a steppingstone for learning. In the first instance, teachers act as educators: They recognize the beneficial role of errors and want to emphasize it. On the contrary, when teachers recognized a sanctioning meaning to errors and ascribed responsibility to students, they used grading to penalize the error. In the second case, teachers acted as gatekeepers by using grading to select deserving students and penalise the others.

Competitive ideologies (Butera et al., 2022) and the stress on school accountability (Figlio & Loeb, 2011) determine the structure, the pedagogy, and the focus of education

systems in neoliberalist societies today. Teachers tend to adapt to requirements and features of the education system in which they work, and, consequently, it may be argued that teachers tend to accentuate their role as gatekeepers instead of as educators (Butera et al., 2021) to fulfil the selective function of education systems. The accentuation of the gatekeeper role may be exacerbated by the use of normative grading for evaluating everyday learning activities. Furthermore, by penalising errors with grades when they are due to a lack of students' commitment, teachers may contribute to perpetuating the negative representation of errors in the learning environment.

1.2. Relational level: Teacher-student interactions around errors

As stated in Chapter 1, cultural values and norms affect social interactions by determining their rules, routines, and characteristics (Mercer & Littleton, 2007). Furthermore, social interactions could be considered the "space" where the learning process occurs (Vygotsky, 1978). The teacher-student relationship represents the core interaction in which shared cultural meanings and learning routines are built. These interactions and routines contribute to establishing a particular learning environment (e.g., classroom climate, Wang et al., 2020). By dealing with students' mistakes, teachers may create an error-friendly environment (i.e., perceived error climate, Steuer et al., 2013) in which errors are framed, used, and perceived as a stepping stone for learning.

Accordingly, Study 2 focused on teachers' error-handling strategies and their impact on students' perceived error climate. We manipulated teachers' responses to students' errors (i.e., positive error-handling vs neutral error-handling condition) by conducting a quasi-experimental pre-test/post-test design research. The main result of this study was that when the trained teachers dealt with mistakes supportively, students perceived a more positive error climate after the lesson than before. This difference was significant only in the positive error-handling condition and not significant in the neutral error-handling condition.

To the best of our knowledge, this study was the first that experimentally demonstrated the impact of specific error-handling strategies on students' perceptions of error climate. As shown in Chapter 3, previous experimental studies on teachers' error-handling strategies assessed various dependent variables (e.g., learning outcomes, Heemsoth & Heinze, 2016) or trained teachers (e.g., Rach et al., 2013) instead of manipulating their strategies. Through Study 2, it was possible to claim a causal relationship between teachers' error-handling practices and students' perceptions of a positive error climate.

This study enriched the literature about the role of supportive teachers' practices in promoting an effective learning environment. By adopting such practices, teachers can create a classroom climate that fosters students' social skills, learning outcomes, and emotional development (e.g., Jeggings & Greenberg, 2009; Reyes et al., 2012). Supportive practices aimed at encouraging students and treating them fairly take place within the teacher-student relationship. Positive error-handling strategies implemented in Study 2 could be considered supportive practices related to errors, intended to encourage and help students by providing positive feedback. Through this feedback, students can start or expand the dialogue around the errors with the teacher (Mehan, 1979), while the teacher creates an emotionally safe environment in which errors are tolerated (Steuer et al., 2013).

1.3. Between relational and psychological levels: from error climate to students' achievements

The last study bridged the relational and psychological aspects of learning from errors. Study 3 set out to test whether students' perception of a positive error climate was associated with learning outcomes via adaptive reactions towards errors (i.e., affective-motivational and action reactions). As hypothesized, the results showed that the perceived error climate was related to affective-motivational reactions, which were linked to action reactions towards errors. In addition, both adaptive reactions were related to better students' learning outcomes. This serial mediation pathway was controlled for error beliefs, age, gender (individual

features), and classroom goal structure (classroom characteristic). In this way, it was possible to test different variables included in the learning from errors model (Tulis et al., 2016).

Results from Study 3 echoed previous research findings on perceived error climate and students' learning achievement (e.g., Grassinger et al., 2018; Steuer et al., 2013) and enriched the literature by supporting the model presented by Tulis and colleagues (2016). In addition, this study further sustains the idea that a supportive and positive classroom environment promotes students' emotions and motivations (e.g., Gasser et al., 2018; Fokkens-Bruinsma et al., 2020; Frenzel et al., 2007; Wang et al., 2020), and thus, foster students' learning outcomes (Hughes et al., 2008; Reyes et al., 2012).

2. General contributions of this dissertation

Beyond the contributions of each study, this dissertation provides a general overview of the role of errors in the learning process and suggestions for educational psychology research. In this section, we outline the three main general contributions of this dissertation.

2.1. The integrated approach: a useful tool to study the learning from errors process

As shown in previous chapters, literature about errors in the learning process has mainly focused on either psychological (e.g., Dresel et al., 2013) or relational (e.g., Steuer et al., 2013; Tulis, 2013) aspects. When proposing their model, Tulis and colleagues (2016) discussed several theories to explain individual processes related to errors as well as how characteristics of the task, the situation, and the environment affect this process. In this dissertation, we attempted to enrich Tulis and colleagues' (2016) model by including findings on relational (such as error climate and teachers' error-handling strategies) and cultural aspects (such as teachers' beliefs and errors meanings) that may influence psychological mechanisms triggered by error feedback (i.e., adaptive reactions towards errors).

Since errors are affective events *per se* (Zhao, 2011) and have a social connotation (Billett, 2012), limiting the explanations of their role in learning to one level of analysis could

lead to misleading or partial conclusions. For instance, Eskreis-Winkler and Fishbach (2019) argued that failure feedback undermines people's motivation and the possibility of learning after failure. The authors demonstrated the negative effect of failing on learning through five experiments. After a learning phase in which participants (i.e., adults of any nationality) received either failure feedback or success feedback (namely, the two experimental conditions), they took part in a test that assessed their performance. Comparing the participants' results between the two conditions, the authors found that people learned less when they failed than when they succeeded in the learning phase. According to the authors, after making mistakes, participants' motivation decreased because they perceived error feedback as threatening. This threat, and the consequently decreased motivation, led to disengagement from learning and people stopped paying attention to information received from the failure feedback.

This article focused only on the psychological level (e.g., perceived threat, personal motivation and commitment) without considering other possible variables that may concur to explain the decrease in performance and motivation. However, the authors clearly stated that "people find failure feedback ego threatening, which leads them to tune out and miss the information the feedback offers. In other words, failure undermines learning." (Eskreis-Winkler & Fishbach, 2019, p. 8). Although this paper reported a strong effect corroborated in five experiments, the authors' conclusions understated the complexity of learning and the multifaceted nature of individual reactions to error feedback. We question neither the scientific value of the results reported in this paper nor the importance of studying psychological and cognitive mechanisms in isolation with a specific methodology. However, the possibility of learning from errors may change according to the person's characteristics and the environment in which errors occur, the moment in which errors happen, and the cultural connotation of making errors.

Differently from this study, Metcalfe (2017) reviewed cognitive and neuropsychological literature on the role of errors in learning, stressing the importance of the learning context. After displaying and explaining several research findings supporting errors increase memory and foster cognitive processes, the author concluded the literature review by stating: “The concern that errors might evoke dysfunctional emotional reactions appears to be exaggerated. Of course, sensitive handling of errors and avoiding gratuitous punishments—verbal or otherwise—is essential. The research reviewed here suggests that teachers and learners alike should be encouraged to be open to mistakes and to actively use them in becoming prepared for the test that counts.” (Metcalfe, 2017, p. 484).

In the same line, Denervaud and colleagues (2020) investigated differences in two cognitive processes triggered by making mistakes between children (from 4 to 15 years old) attending traditional or Montessori schools. The authors measured the post-error slowing (PES), the usual pause after an error detection, and the post-error improvement in accuracy (PIA), the behavioural adjustment that occurs after making mistakes. Both are cognitive mechanisms enacted during the performance monitoring, one phase of the self-regulated learning process. The study aimed to understand differences throughout ages in the performance monitoring processes and observe how this development changes in different learning contexts. Besides considering differences due to the age of participants, the authors interpreted psychological-related results in the light of environmental characteristics, referring to how traditional and Montessori schools frame errors and provide error feedback. For instance, in Montessori school contexts, teaching relies on not competitive peer-to-peer strategies, which may lead to more effective use of errors for learning. Conversely, teachers in traditional schools tend to give evaluative feedback after errors, thereby transmitting a negative and socially stigmatised value of making errors.

These two last examples emphasised the pivotal role of relational and cultural aspects in determining how errors are used and perceived in learning environments. Building new knowledge (i.e., learning) involves mental processes that are socio-culturally induced and supported (Hatano & Inagaki, 2003). In the same vein, learning from errors depends on mental mechanisms (i.e., self-regulated processes) that may be induced and sustained in error-friendly environments where the positive value of making errors is transmitted through teachers' supportive practices. The first general contribution of this dissertation lies in trying to explain learning from error in an integrated way, considering the complex interplay between different variables that represent different levels of analysis.

2.2. Interconnections between levels of analysis

Another general contribution closely related to the previous one refers to the interconnections between the three levels of analysis. In the theoretical part (i.e., chapters 2-3-4), the different levels of analysis were separated and differentiated, as depicted in Figure 1 (Chapter 1). However, in each theoretical chapter, the variables described are always influenced and connected with variables that belong to another level. For instance, in Chapter 3, we described teachers' error-handling strategies as a relational variable, even though cultural aspects influence these variables (i.e., the structure of the lesson or teachers' beliefs about learning).

This overlap and interconnections are evident also in the empirical part. In Study 1, cultural level is represented by teachers' beliefs and educational system features that may influence teachers' practices. Teachers' practices represent how teachers interact with students and errors during learning activities, and thus, they represent the relational level. This level is the focus of Study 2, in which teachers' error-handling practices are related to students' perceptions of error climate. Teachers' error-handling practices are affected by cultural variables and affect the error climate.

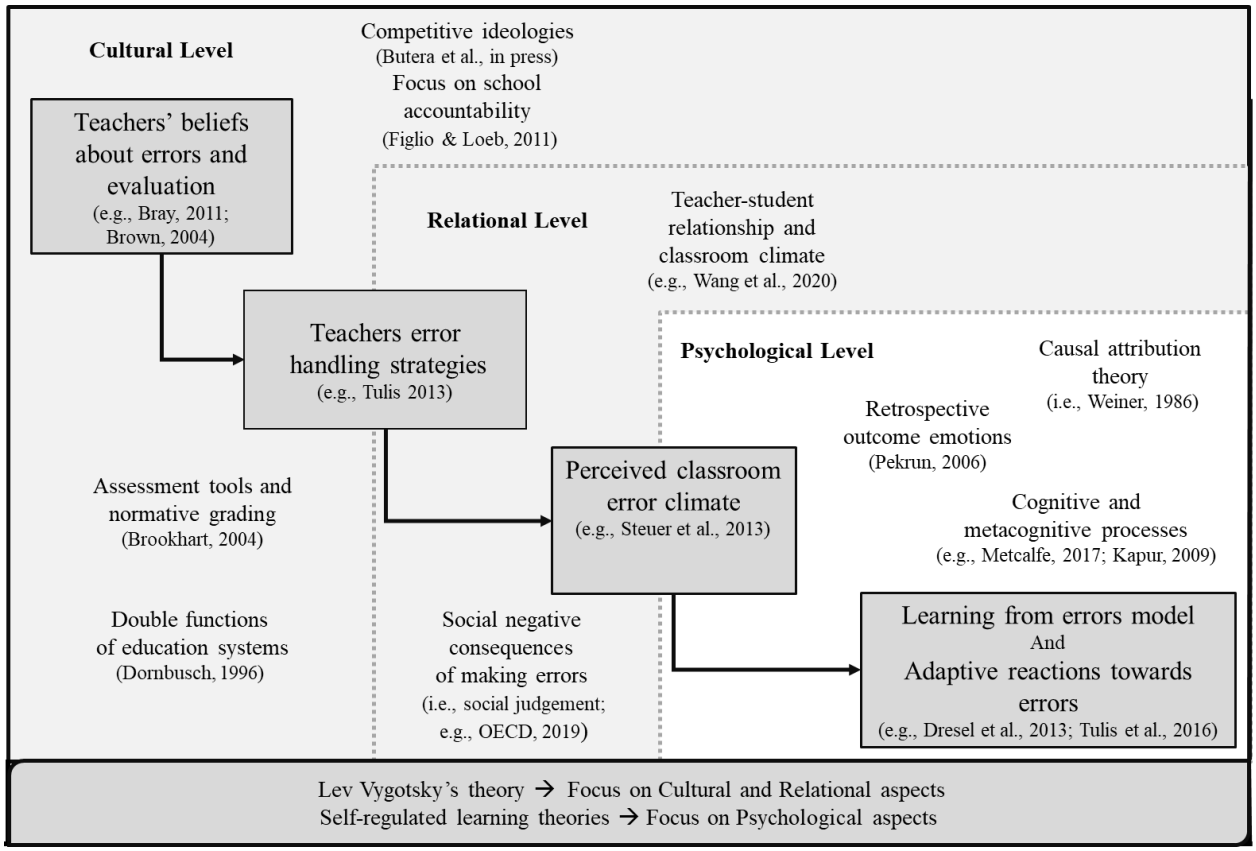
These interconnections between the three levels mirror the conceptualisation of Mercer and Littleton (2007) and the complexity of the two theoretical theories used as a background for the dissertation, namely Vygotsky's theory and Self-regulated learning theories. As stated in Chapter 1, these frameworks were used to describe how psychological, relational and cultural aspects have been conceived in the dissertation. Self-regulated learning theories were the basis for understanding the interplay of different psychological dynamics (e.g., emotional, motivational, cognitive, and metacognitive). Vygotsky's theory provided an innovative conception of culture and social interactions we adopted here: they are determinant factors for child development and learning.

Neither of these theories ignores the importance of all these aspects. On the one hand, Self-regulated learning theories recognise the role of cultural and relational context. On the other, the internal psychological dynamics are an important part of Vygotsky's theory (as expressed in Chapter 1). As a result, the interconnectedness of the three levels of analysis is well portrayed in both these background theories as well as in the theoretical approach of the dissertation.

Therefore, the second major contribution of this dissertation is to reconsider boundaries between levels, stressing the interconnections between them. Figure 1a represents a revised version of Figure 1 (Chapter 1). As in Figure 1, each theory mentioned in the theoretical part is placed on the corresponding level (i.e., Pekrun's theory on the psychological level). Unlike Figure 1, the overlap and interconnection between levels are represented by the error-related variables studied in this dissertation. This new figure portrays a revised version of the theoretical model, although the links between variables can not be demonstrated entirely at the empirical level (see Limitations and Future Research section).

Figure 1a

Theoretical Interconnections Between the Three Levels of Analysis



2.3. Learning from errors: Is it always possible?

The third contribution of this dissertation, closely related to the first, is the attempt to answer the question: Is it always possible to learn from errors at school? Our multilevel approach provides a complex response to this question.

Considering cultural aspects of learning means interpreting teaching as agents of social influence (Butera et al., 2021) and teachers' practices as an expression of broader cultural values. Competitive ideologies and a school accountability focus may be linked with a negative meaning of making errors because errors indicate a decrease in the students' performance. To use errors as a learning opportunity, teachers should adopt supportive strategies to deal with errors. These strategies are related to teachers' beliefs that errors have pedagogical meaning, namely, errors are due to a lack of students' understanding and should

be included in the learning activities. On the contrary, if teachers ascribe responsibility for the error to pupils, their responses may become maladaptive. Furthermore, because of their negative interdependence with grades, when teachers must assess pupils using normative grading, errors risk turning into a sign of failure. Therefore, only errors that acquire pedagogical meaning seem to be related to more supportive and positive teachers' error-handling strategies in evaluative and not evaluative learning activities.

Only teachers' supportive and positive error-handling strategies, such as discussing the mistake with the whole class and discouraging classmates' negative reactions, promote a positive error climate. Study 2 showed that all these strategies contribute to establishing a more positive perceived error climate. Learning in a supportive error climate means seeking advice, admitting and discussing errors, and discovering their causes instead of covering them up or blaming each other (e.g., Dyck et al., 2005). Therefore, errors may be viewed as a stepping stone for learning when students perceive to be supported by the teacher and classmates and when they are scaffolded in using errors concretely in their learning activities.

Perceiving to be part of an error-friendly environment supports students' adaptive self-regulation processes triggered after making mistakes. Indeed, by testing a comprehensive model, we demonstrated that perceived error climate has a key role in fostering adaptive reactions towards errors above and beyond other variables (Study 3). These results supported the psychological part of the theoretical model presented by Tulis and colleagues (2016), pointing out that students who maintain positive emotions and motivation after the error detection also adopt more adaptive cognitive strategies and behaviours, which are useful to foster learning. Therefore, starting from the relational level and moving into the psychological, it may be argued that learning from errors is possible when self-regulated learning processes are adaptive and occur in an error-friendly environment.

To summarise, our findings indicate that, under some conditions, errors can be beneficial to learning. Errors should be perceived favourably by students, handled supportively by teachers, and not directly related to a decrease in the obtained evaluation to foster learning.

2.4. The role of teachers in promoting learning from errors

The third general contribution of this dissertation is related to the role of teachers in supporting learning from errors. Teachers are the key factor in all three studies and at all three levels of analysis, albeit in different ways. They represent the cornerstone between cultural, relational, and psychological levels. In Study 1, teachers' beliefs and practices were the targets of the investigation. In Study 2, teachers' error-handling strategies represented the manipulated variable that affected pupils' perception of error climate. In Study 3, how teachers usually react to errors in the classroom was assessed indirectly through the perceived error climate questionnaire.

It is not surprising that teachers have been defined as the most powerful factor influencing learning (Hattie, 2009). Teachers promote students' motivation, achievement, and self-efficacy (e.g., Lee, 2012; Ruzek et al., 2016) as well as create a positive emotional and motivating classroom climate (e.g., Rach et al., 2013; Wang et al., 2020). Our results contribute to enriching literature on the role of teachers in learning in two ways. First, our findings show how supportive error-handling strategies influence students' perceptions of a positive error climate, which in turn supports the self-regulated learning processes triggered by making mistakes.

Second, our findings emphasise that teachers' practices must be interpreted in the light of the cultural influences of the context of which they are part. Describing teachers as agents of socialisation means considering that teachers do not work in a sociocultural vacuum. Social pressure and cultural values affect their teaching. Valli and Buese (2007) argued that high-

stakes policy directives promote an environment in which teachers use practices different from the *best practices* they are recommended to use. This misalignment contributes to increasing teachers' stress levels, discouragement, and role ambiguity. Accordingly, our results showed that teachers found dealing supportively with students' errors (best practice) while using grades (high-stake policy directives) demanding. Strategies teachers adopt, and their impact on the learning process and students must be analysed considering their social role that is determined by social norms and cultural shared values.

To summarise, the third contribution is pointing out the importance of the teachers' role in promoting learning from errors, which is both essential and complex. Supportive error-handling strategies can have an impact on the establishment of a positive error climate, especially if the teacher assumes the role of educator rather than gatekeeper (Butera et al., 2021), which is closely connected to the functions of the education systems (Darnon et al., 2009).

3. Limitations and future directions

Besides the limits of each study reported in the related chapters, this dissertation has some general limitations that should be addressed. We list and explain these limitations and provide suggestions for further investigation.

3.1. Only a theoretical link

The integrated approach and the three levels of analysis described above provided a comprehensive overview of different aspects that may affect learning from errors. Even though the three empirical studies reflect the multi-level approach of the dissertation, they were conceived as three different lines of research. Therefore, it is not possible to claim a methodological continuum and generalizability of the results between the three studies. This limitation is due to the different samples and different subjects investigated.

As for the different samples, Study 2 and Study 3 assessed middle and primary school students, respectively. Pupils of Study 2 attended the last year of primary school (M_{age} = 10.38, SD = 0.54), whereas students of Study 3 attended grades 6 – 7 – 8 of middle school (M_{age} = 11.98, SD = 0.79). Even though the mean age of participants did not vary considerably, primary and middle schools have specific environmental characteristics. For instance, in the Italian Education System, the two school levels differ on the timetable schedule, subjects taught, the number of teachers, and the teacher-student relationships. A perfect overlap between the two school levels is not plausible, and thus, generalising Study 2's results to a middle school sample or vice versa is not methodologically correct.

As for the different subjects, Study 2 was carried out during civic education lessons, whereas Study 3 was implemented during mathematics classes. The two different subjects were chosen according to the studies' research questions and methodologies, providing reasons behind this choice. Nevertheless, errors may be perceived, detected, and corrected differently in different domains. For instance, a mistaken computation in mathematics may trigger different reactions than a grammar error in a text or a flawed pronunciation in English as a foreign language. Accordingly, Tulis and colleagues (2018) found that reactions towards errors and error beliefs are domain-specific (i.e., mathematics, German and English as a foreign language). In addition, while analysing teachers' interviews in Study 1, the data were not divided according to the subject taught by the participants—however, some differences emerged between how mathematics and English as foreign language teachers considered an error.

For these reasons, further results are needed to understand the replicability of Studies 2 and 3 in other school levels. Furthermore, it would be recommended to test the extent to which classroom variables change in different school domains and according to instructions and teaching related to each subject. Finally, an analysis of teachers' beliefs about errors

differentiated for domains could be useful to understand whether teachers' beliefs and practices change according to the subject taught. Expanding these lines of research may allow generalising results about aspects that may affect learning from errors. In this way, it will be possible to link different levels of analysis theoretically and empirically.

3.2. Other variables involved in the learning from errors process

Another general limitation concerns the variables measured and studied. As for the cultural level, we looked at teachers' beliefs about errors and their link to normative grading as an expression of the cultural values that dominate the school (i.e., competition and stress on students' performance). In discussing the findings of Study 1, it emerged that, in addition to cultural values (e.g., competitive values), there are several social norms that influence teaching, such as the norm of internality (e.g., Dubois, 1994) or the norm of effort (e.g., Matteucci & Gosling, 2004). The latter is closely tied to how teachers assign responsibility for the error to students, which impacts how teachers act after a student fails. In this regard, it would be interesting to investigate the functioning of these social norms by connecting them more directly to the use of errors and assessment in learning.

Peer relationships were excluded from our analysis at the relational level, despite their importance in creating supportive and positive learning environments (e.g., Wang et al., 2020; Wentzel, 2017). Peer reactions represent one dimension of the perceived error climate (Steuer et al., 2013), and peers' judgment was listed by the participants of Study 1 as a possible factor that causes students' fear of making mistakes. Furthermore, some of the error-handling practices proposed by Tulis (2013) and implemented in Study 2 during the fictitious lesson were based on the involvement of classmates, such as, for instance, discussing the error with the whole class and stopping the classmates' reactions. Therefore, the quality of peer relationships and students' perceptions of their classmates' reactions should be considered in future studies.

Finally, at the psychological level, we assessed error beliefs (Studies 2 and 3) as a personal variable that may impact the learning from errors process, achievement goal emotions (Study 2) as an outcome variable and adaptive reactions towards errors to assess self-regulation processes. We did not consider other important psychological mechanisms triggered by making errors, such as, for instance, causal attributions. Although we discussed their role in the theoretical part, we did not assess causal attribution in the empirical studies. However, only Grassinger and Dresel (2017) studied the relationship between causal attributions and adaptive reactions towards errors, and thus, other empirical findings should be provided. In addition, self-efficacy beliefs or students' past achievement, not yet studied in previous research, may be linked to the adaptive reactions towards errors. Since these variables are related to persistence on the task even after a failure (e.g., Usher & Schunk, 2018), further research should investigate the possible effect of self-efficacy beliefs on students' self-regulation process triggered after errors.

4. Practical implications

Our results suggested that teachers' supportive practices are pivotal in establishing an error-friendly environment that, in turn, promotes students' adaptive self-regulation processes and foster learning outcomes. In addition, these practices were related to teachers' beliefs about the meanings of errors in learning and changed according to some educational systems features (i.e., grading assessment). Since teachers' practices play such an essential role in promoting learning from errors, it may be possible to draw ideas from our results to set educational training interventions targeted to teachers' professional development.

According to Jurasaite-Harbison and Rex (2010), professional development refers to formal training based on workshops, presentations and projects in which teachers are involved. Professional development enhances teachers' satisfaction, commitment to innovation, self-efficacy, and teaching quality (see Gore et al., 2017), and thus, is

fundamental for school improvement and education systems reform (Brendeson, 2000). However, some scholars highlighted a lack of methodological rigour (e.g., Guskey & Yoon, 2008) and a clear link with real practices (Gore et al., 2017) in several teachers' professional development training, making interventions less effective.

Among other kinds of teachers' training regularly implemented in schools, here we refer to video-based interventions. Video-based self-reflection and feedback interventions are characterised by presenting to and discussing with teachers videotaped lessons (their lesson, a peer one, or a fictitious one) and supporting them in reflecting on teaching. Therefore, this kind of intervention is highly linked with teachers' practices, and there are several examples of implementation of video-based training with a rigorous methodology (e.g., Lesson Analysis Framework, Santagata et al., 2007; Santagata, 2009). These interventions have been implemented with either in-services or pre-service teachers, showing positive outcomes for both these categories (e.g., Brouwer et al., 2017; Rosaen et al., 2013; Santagata & Angelici, 2010; Santagata & Yeh, 2014). Interesting results have been found about the effects of using video-based interventions on teachers' interactional style (Brown & Kennedy, 2011), classroom management practices (van der Boghet et al., 2014), learning-from-teaching competencies (Santagata et al., 2018), and teachers' cognition, motivation, classroom practices (for a review, Gaudin & Chalies, 2015). Furthermore, Santagata and colleagues (2018) found that pre-service teachers' beliefs about how students learn mathematics and mathematics itself changed over time when the participants of a video-based intervention had the opportunity to watch videos on students solving mathematics exercises.

Video-based interventions effectiveness stem from making students learning visible to teachers (Santagata & Guarino, 2010) and deconstructing the classroom environment complexity providing teachers with the ability to interpret relevant learning-related events (Gaudin & Chalies, 2015; Kersting et al., 2012). Indeed, by observing themselves or

colleagues, teachers have time to reflect on their teaching in collaboration with other teachers, co-constructing interpretations on live observations while being scaffolded by educators (Santagata et al., 2018). This technique allows extensive access to classroom interactions and provides teachers with examples that function as sources of uncovering, clarifying, discussing, and challenging their teaching and their theories about teaching (Abell & Cennamo, 2004). The self-reflection process should be structured and guided for pre-service (Santagata et al., 2007) and in-service teachers (Santagata, 2009).

Video-based interventions may be employed to support teachers in becoming aware and reflecting on their error-handling practices, as shown by Santagata and Bray (2010). In their study, the authors proposed a professional development video-based intervention focused on students' mathematics errors. The findings showed that teachers became more aware of their students' misconceptions, mathematical ideas, and representations, as well as they demonstrated interest in learning new and innovative instructional strategies. In addition, teachers changed their practices, such as focusing more the lesson on students' errors and giving supportive feedback to unveil their mathematical idea. When dealing with students' errors, teachers often adopt several practices, most likely, without having the time to analyse the situation. Videotaping a lesson and focusing teachers' attention on how they have managed students' errors may help them deconstruct the situation in which the error occurred and reflect on their practices. The videotaped lesson can be fragmented, interrupted and watched several times, making it easier to focus on a particular moment of the lesson.

Furthermore, video-based training effectively makes students' content learning and reasoning visible to teachers, and thus, we may argue the same for flawed students' reasoning processes. Watching videotaped lessons could be a valid instrument to help teachers become more and more expert in detecting errors and using supportive practices, which may be helpful to guide students in understanding the misconceptions. Pre-service teachers could

primarily benefit from that since they could be unprepared to support cognitively students who made mistakes.

In Chapter 3, we presented studies based on teachers training on error handling strategies (e.g., Rach et al., 2013) that could not effectively modify teacher practices aimed at using errors concretely as an opportunity to learn during learning activities. Video-based interventions may be considered a suitable tool to support teachers in improving their strategies to use errors concretely. These interventions may be implemented to reflect on teachers affective and emotional reactions and understand how cognitively support the student who made a mistake and use errors as a steppingstone for learning.

To conclude, teachers are the most powerful variables that affect learning, and, consequently, excellence in education could be reached if teachers learn how to make their students learning visible and if their conceptions and beliefs become the subject of debate and investigation (Hattie, 2009). Therefore, teachers need to become aware of their role in promoting a positive meaning of errors through their practices. They need to be guided in understanding how their students can be supported when they fail and knowing how their cultural beliefs (Santagata, 2004) and structural features of their job impact their teaching. Video-based training may be an effective professional development intervention for encouraging teachers to reflect on (and improve) their error-related practices. Researchers and educators can support teachers in debating, refusing, examining, and challenging their error-related practices and beliefs about errors by employing video-based interventions. To give this support to teachers, researchers and educators must speak the same language as teachers. It implies that researchers and educators must enter the world of schools without imposing a resolutive recipe. On the contrary, they should include teachers in an empowerment process in which teachers are the promoters and protagonists of their education, development, and improvement. In this way, teachers can become agents of change.

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