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Supportive Error Feedback Fosters Students' Adaptive Reactions towards Errors: Evidence from a Targeted Online Intervention with Italian Middle School Students

Short title: Error feedback and students' reactions towards errors

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Abstract

Background. Although it is well established that students' adaptive reactions towards errors promote learning outcomes, little is still known about the role of error feedback in promoting these reactions.

Aim. Through a targeted intervention based on an online teaching unit, this study aimed at testing whether supportive error feedback promotes more adaptive students' reactions towards errors and higher learning outcomes.

Sample. A total of 250 (M_{age} = 12.18, *SD* = .89; 46.4% girls) Italian middle school students took part in the intervention. Students were randomly assigned to either a discouraging error feedback condition (*n* = 124) or a supportive error feedback condition (*n* = 126).

Method. The intervention consisted of an online teaching unit, which students filled in at home, that was divided into pre-test, intervention and post-test phases. During the intervention, students replied to training questions and, every time they made an error, informative feedback appeared: supportive smileys and sentences in the supportive feedback condition, and disappointed smileys and sentences in the discouraging feedback condition. Before the intervention, students filled in the pre-test and after the intervention students reported their reactions towards errors and filled in the post-test.

Results. Receiving supportive feedback resulted in more adaptive affective-motivational reactions towards errors, which in turn resulted in more adaptive action reactions towards errors. Differently from our expectations, action reactions towards errors were not related to the post-test scores.

Conclusions. Our findings can inform the development of online teaching units that promote an error-oriented approach.

Keywords: error feedback; reactions towards errors; targeted intervention; middle school students; learning from errors

Introduction

Several studies have shown that errors can play a key role in promoting learning (e.g., Metcalfe, 2017). This potential positive role for learning can be exploited if errors are made in an error-friendly learning environment (e.g., Steuer et al., 2013) and if they are included rather than avoided in the learning activities (e.g., Heesmoth & Heinze, 2007). In such conditions students may react to errors adaptively, maintaining high motivation and positive emotions to adopt useful cognitive and metacognitive strategies to understand and overcome the errors (Dresel et al., 2013). According to the theoretical model proposed by Tulis and colleagues (2016), to make these self-regulatory processes start, students have to detect errors. During learning activities, students may detect errors by themselves, or they may receive external feedback after an error (*error feedback* from now on), namely simple information that helps them to know that there is a mismatch between the expected outcome and the actual one (i.e., the error).

Rooted in the learning from errors model (Tulis et al., 2016), the present study sought to experimentally test if supportive error feedback promotes students' adaptive reactions towards errors and eventually learning outcomes. More precisely, by manipulating the type of feedback received after errors in terms of emotional facet (i.e., supportive or discouraging), the study assessed differences in the level of students' affective-motivational regulations, which in turn are supposed to influence metacognitive and cognitive strategies, which may promote better learning outcomes. What is more, this study used for the first time an experimental design to test the effect of different error feedback on learning outcomes via adaptive reactions towards errors, going beyond previous studies that were merely correlational and focused on students' perceptions of contextual features (i.e., classroom error climate; Soncini et al., 2022; Grassinger et al., 2018) rather than the actual received feedback.

Finally, the experimental manipulation is embedded into a targeted intervention (Harackiewicz & Priniski, 2018) conducted in an online learning environment during the school

year 2020-2021 in Italy. At that time, Italian students were used to online learning due to the school closures enforced to stop the COVID-19 pandemic. This is an important feature of the present research because it may add an innovative piece of knowledge to the debate about how to strengthen school digitalisation and advance education system capabilities to provide online education at different levels, both key goals for the European Commission Digital Education Action Plan 2021-2027 (European Commission, 2021) and long-term responses to the COVID-19 crisis (Guppy et al., 2022; OECD, 2022; Zancajo et al., 2022).

Learning from Errors: A Matter of Adaptive Reactions

When speaking about errors in the learning process, scholars have usually referred to two main approaches. The first, based on behavioural theories, argues that errors are negative signals that need to be avoided (Ausubel, 1968; Bandura, 1986). The second, derived from constructivist theories, argues that errors are important aspects for improving learning and they should be included in the learning process (Metcalfe, 2017). The theoretical model elaborated by Tulis and colleagues (2016) reflects the second approach and provides a complex overview of the different self-regulation processes that promote learning from errors. Inspired by Lazarus' (1991) appraisal theory and various self-regulated learning theories (e.g., Boekaerts, 2003; Wolters, 2003), the authors (Tulis et al., 2016) argued that, after error feedback or the detection of errors, learners must assess the significance of a discrepancy between the expected result and the actual outcome (i.e., the error). This first appraisal is characterised by emotions that learners are unable to fully explain and understand, such as surprise or disappointment. After this appraisal, a second appraisal emerges and it pertains to an indirect evaluation that helps learners gain a deeper grasp of the situation, by assisting them in determining the reasons for the error as well as the personal skills required to overcome it.

Emotional regulations, in turn, trigger motivational regulations. Maintaining high levels of motivation is crucial to allow students to keep up interest and engagement in understanding the

error. Consequently, emotional and motivational regulations are assumed to foster cognitive and metacognitive functioning which are particularly important in learning from errors. For instance, maladaptive strategies, such as suppression or ruminations, may hinder the possibility of deeply understanding the error. Similarly, a negative evaluation of the performance progress caused by receiving negative error feedback may increase the number of useless learning procedures adopted to overcome the error (Tulis et al., 2016).

Emotional-motivational regulation as well as cognitive and metacognitive strategies elicited and implemented after making an error have been conceptualise by Dresel and colleagues (2013) as two distinct and connected reactions towards errors. The *adaptive affective-motivational* reactions towards errors refer to positive emotions and sustained motivation in performing the task after making errors, whereas *adaptive action* reactions towards errors are the set of learning strategies and actions addressed to understand and overcome the error.

The few studies conducted so far on the adaptive reactions towards errors corroborated the distinction between the two reactions (Grassinger & Dresel, 2017; Steuer et al., 2022; Tulis et al., 2018). Following the theoretical model of Tulis and colleagues (2016), a correlational study (Grassinger et al., 2018) showed that students' perception of being part of an error-friendly environment promoted more adaptive affective-motivational reactions towards errors, which in turn fostered more action reactions towards errors. Then action reactions towards errors were related to students' better achievement (measured as the difference between pre-post test results in a math test). The same indirect relationship was found in another correlational study (Soncini et al., 2022) that measured math grades as students' learning outcomes and tested a model that encompassed students' error beliefs as well, i.e., the belief that errors are useful for learning, which are strong predictors of adaptive reactions towards errors (Tulis et al., 2018). These findings support the idea that changes in cognitive and metacognitive strategies to overcome errors are fundamental to promoting learning after emotional and motivational regulation.

The studies conducted so far on the role of adaptive reactions towards errors in promoting learning, however, were based on correlational and focused on the relationship between these reactions and students' perceptions of classroom error climate (Soncini et al., 2022; Grassinger et al., 2018). Thus, they explored the students' perceptions and their reactions towards errors by referring to in-person situations, where learning activities are performed in classroom settings characterised by a particular error climate (i.e., tolerance towards errors or error-avoiding attitudes; Steuer et al., 2013), and where the presence of the teacher and the classmates is salient. Going beyond these findings, the present study sought to further explore the relationship between affective-motivational reaction, action reaction and learning outcomes through an experimental design where the independent variable is not the students' perception of classroom error climate, but the error feedback students receive during an online learning activity.

Error Feedback in the Light of the Learning from Errors Model

Feedback is considered an important element for improving students' learning (Hattie & Timperley, 2007; Hattie & Zierer, 2019). Feedback provides information about one's performance and understanding (Hattie & Timperley, 2007) and scholars have described different types of feedback (e.g., minimal, confirmative, and corrective; Kim et al., 2018; Wisniewski et al., 2020) as well as several features that make it extremely effective (e.g., task- and goal-directed, specific, neutral and informative; Thurlings et al., 2013; Wisniewski et al., 2020). Narrowing the concept, error feedback can be defined as information on a mismatch between an expected outcome and the actual outcome. In other words, error feedback is provided after making an error during a task or learning activity.

Several error-centred learning approaches recognised the key role of error feedback to promote learning from errors. In the productive failure framework (Kapur, 2018; 2014; Shina & Kapur, 2021), students are helped to detect their errors through error feedback provided by a more expert person while engaging in new tasks that may result in failures. In Error Management Training (EMT), developed by Frese and Keith (2015), providing error feedback to learners

increases the possibility that they engage in a process that leads to a better understanding of the problem and better learning. Other scholars tested interventions based on eliciting errors and encouraging students to detect them after receiving error feedback proving their effectiveness compared to error-avoidance approaches (e.g., Heemsoth & Heinze, 2016; Lee, 2020; for a literature review Metcalfe, 2017).

Recently, the debate about the effectiveness of making errors to promote learning has been relighted by experimental studies that compared receiving error feedback and success feedback (i.e., feedback provided after a correct answer). For instance, Eskreis-Winkler and Fishbach (2019) found that learners who received success feedback outperformed those who received error feedback (called by the authors *failure feedback*). According to the authors, failure feedback is ego-threatening, decreases motivation, and thus, undermines learning. Keith and colleagues (2022) replicated the experiment carried out by Eskreis-Winkler and Fishbach (2019), showing, on the one hand, that receiving success feedback promotes learning more than receiving error feedback, and, on the other hand, that this difference decreased considering the type of feedback provided and when incentives to learn from errors were introduced.

Other studies compared different kinds of error feedback in terms of the amount of information provided, namely, confirmatory (i.e., knowing only if the response is correct or wrong) vs. informative (i.e., providing the right response). Kim et al. (2018) compared informative vs. confirmatory success feedback and error feedback. Their results showed that only when receiving informative feedback, success feedback promotes better performance in a post-test task than error feedback. Confirmatory feedback did not affect differently learning performances in the post-test. Woo et al. (2015) tested the effects on brain activation during failure processing of informative and confirmatory error feedback, manipulating also the emotional activation related to it: success feedback, low-negative error feedback and high-negative error feedback. To manipulate the emotional activation, the authors presented a human face showing anger and a negative sentence (low-intensity and high-intensity negative error feedback) vs a smiling face and a supportive

sentence (positive success feedback). The authors did not find significant results on behavioural aspects (i.e., differences in reaction time at the post-test) between informative vs. confirmatory feedback or between high-intensity and low-intensity negative feedback, but only differences in brain activation highlighting how the kind of feedback provided affects brain region involved in error processing.

Although this recent evidence supports the important role of the type of feedback in promoting positive outcomes in students, the studies were conducted in the laboratory, with adults, and were based on comparing error feedback with success feedback rather than comparing error feedback that supports students and error feedback that discourages students. To better understand the importance of this nuance, we draw here on studies that have focused on teachers' responses to errors in a school learning context. For instance, Santagata (2004) found that Italian and U.S. teachers reply to students' errors during learning activities in three different ways, by using aggravating, mitigating and neutral responses. The first group encompasses reactions and feedback which are more maladaptive, such as underling the negativity of making an error. The second group encompasses sentences aimed to support students in understanding errors. The third group encompasses all the other strategies not coded as aggravating and mitigating. Results also showed that teachers tend to use more mitigating and neutral strategies than aggravating, supporting the idea that replying positively to errors is common during learning activities.

Likewise, by videotaping German teachers, Tulis (2013) found that they responded to errors by adopting adaptive (i.e., praising the student), maladaptive (i.e., showing signs of upset and shaking the head), or neutral (i.e., giving the right response after a students' errors) practices. Teachers' responses to errors affected how students perceived errors and their emotions during learning. Based on the results of Tulis (2013), Soncini et al. (2021) showed that adaptive teachers' error-handling strategies promoted students' perceptions of being part of an error-friendly environment, and affected their learning emotions, further corroborating the key role of teachers' practices and feedback on how students view errors. In these studies, the affective reaction of

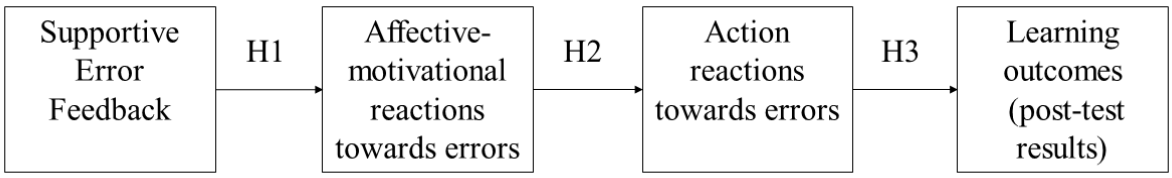
teachers is a pivotal feature of the responses they provide after an error. The affective connotation of teachers' responses may emerge as soon as the teacher provides error feedback, simply indicating that an error just occurred (e.g., rolling eyes while pointing out the error to the student).

The Present Study

Combining the evidence on error feedback literature and the learning from errors model proposed by Tulis and colleagues (2016), the present study aims to test whether different kinds of error feedback (supportive vs. discouraging) promote students' reactions towards errors and eventually learning outcomes. More precisely, we experimentally manipulated the emotional aspect of error feedback, to test whether supportive error feedback promotes adaptive reactions towards errors more than discouraging error feedback (H1). These adaptive affective-motivational reactions are expected to be related to more adaptive action reactions towards errors (H2), which, in turn, are supposed to be related to higher learning outcomes, measured as scores of a post-test task (H3; Figure 1).

Figure 1

Hypothesised Indirect Model



In terms of error feedback used, in the present study, we consider the simplest and more immediate error feedback students may get, the one that helps students to know if their learning outcomes meet the expected responses (e.g., "Yes!", "Right", "That's wrong" or non-verbal behaviour). This feedback mirrors teachers' reactions to errors observed by Santagata (2004) and Tulis (2013) and is framed here as the first step to detecting an error and the starting point of self-regulatory processes described by Tulis and colleagues (2016). This kind of feedback has been

called minimal feedback (Finn & Metcalfe, 2010), corrective feedback (Hattie & Timperley, 2007), or confirmatory feedback (Kim et al., 2018) in previous literature.

To test these hypotheses, we created an intervention where students received either discouraging error feedback or supportive error feedback after every error they committed while learning. The intervention consisted of an online teaching unit about European Union Institutions that participants (middle school students) filled in at home as a homework activity. During the teaching unit, we assessed other variables used as controls. Since error beliefs are closely linked to adaptive reactions towards errors - that is, the greater the belief that errors are useful for learning, the higher the adaptive reactions towards errors (Soncini et al., 2022; Tulis et al., 2018) - we accounted for error beliefs. Furthermore, before the manipulation, students completed a pre-test to account for potential differences in pre-test scores between the two experimental groups. Gender was also included in the model as a control, to detect possible gender differences already found in several educational domains (for literature reviews, Logan & Johnston, 2010; Kulturel-Konak et al., 2011; Sidding & Scherer, 2019; Su et al., 2023).

This experimental study may contribute to the literature by filling in some gaps. Considering studies on error feedback (e.g., Keith et al., 2022), they focus especially on comparing success feedback and error feedback instead of exploring the difference between supportive or discouraging error feedback. Furthermore, these studies missed ecological experimental settings, since most of them were carried out in the laboratory with adults and not in a classroom. In the same line, studies on the learning from errors model were mostly correlations (e.g., Soncini et al., 2022; Grassinger et al., 2017; Steuer et al., 2013), besides Soncini et al. (2021) where different teachers' error-handling strategies were manipulated to assess effects on students' perceptions of classroom error climate rather than on reactions towards errors and learning outcomes.

Materials and Method

Participants

To determine the sample size for the intervention, we considered the medium-to-large effect sizes of our previous experimental study (d = 0.83; Soncini et al., 2021), in which teachers' error-handling strategies were manipulated, as well as of a correlational study (d = 0.74; Soncini et al., 2022) on the association between students' perceived classroom error climate and affective motivational reactions towards errors. With GPower (Erdfelder et al., 1996), we computed the power analysis with the smallest effect size (0.74). The results indicated that a total sample of 50 participants in each group was needed to detect a similar effect size, comparing independent groups means, with 95% of power and alpha error probability set to .05. This power analysis was based only on the detection of medium effect on the first relationship under scrutiny (error feedback-affective motivational reactions towards errors). Thus, we decided to collect a larger sample than the one suggested by the analysis, as large as the participation of voluntary teachers allowed it to be.

A total of 345 students were asked to participate in the project. Among these students, 268 completed the teaching unit (some of them did not have the consent form and others were absent when the teachers sent them the material). We excluded 10 participants who did not fully complete the teaching unit and 8 participants who completed the teaching unit twice. The final sample comprised 250 middle school students (M_{age} = 12.18, SD = 0.89; 46.4% girls; 97% born in Italy; 14.5% bilingual; 8.8% with Specific Learning Disabilities certification; n = 105 in the 6th grade; n = 92 in the 7th grade; n = 53 in the 8th grade). The students were randomly assigned to two experimental conditions: 124 (49.6%) students in the discouraging feedback condition and 126 (50.4%) students in the supportive feedback condition. We checked for possible differences in demographic variables and pre-test scores between the two groups of participants. Only the age of participants differed between the two groups, $t(241) = 1.83$, $p = .03$, highlighting a slightly lower mean age of students in the supportive (M_{age} = 12.07, SD = 0.84) than in the discouraging feedback

condition (M_{age} = 12.28, SD = 0.93). Because of this difference, we controlled for age in the main analysis.

Procedure

Before starting the data collection, the Ethical Board of the second and third author's University approved the research project (Protocol n. 6928, 18/12/2020). We contacted several schools in one Italian region by e-mail. Four schools accepted to take part in the project and four teachers decided to collaborate with the research group. We collected parents' consent forms, and they were fully aware of the goal of the intervention, whereas students only knew they were supposed to fill in an online teaching unit as homework.

The research group provided teachers with the material to implement the intervention. The material comprised (1) an explanation letter for the teachers to present the intervention to the students according to the protocol, (2) a link to the teaching unit delivered via Qualtrics software (Qualtrics, Provo, UT), and (3) a debriefing file to be handed to the students at the end of the study. The data collection took place in May 2021, when students and teachers were used to completing tasks online and by technological means as the school closures due to the COVID-19 pandemic had made these tools part of their school habits. It is important to note, however, that schools were fully open during the data collection.

The teaching unit (Appendix 1) was divided into three sections: "Do you really know EU?", including socio-demographic questions, the pre-test questions and the error beliefs scale, two control variables; "Let's learn together!", including the feedback manipulation (supportive vs. discouraging) and the reactions towards errors scale, to measure the mediators; "Look what we have learned!", which included the post-test and the manipulation check questions. The topic was chosen to avoid as much as possible the effect of gender stereotypes mostly related to science (Miller et al., 2015), and to meet the Italian middle school requirements for including Civil Education units in the teaching programs (Ministry of Education, Law 92/2019).

The learning phase consisted of twelve training questions about the topic of the teaching unit. Every time a student made an error on a question, a smiley and a sentence appeared: in the supportive feedback condition the smileys were smiling and happy and the sentences were supportive and motivating (e.g., "Don't be worried: you will learn from this mistake"); in the discouraging feedback condition the smileys were disappointed, and the sentences emphasised the error (e.g., "Oh no! The answer is wrong"). This kind of feedback proposed an affective reaction after the error (the smileys), which mirrors the affective reactions of teachers during in-person learning situations (Santagata, 2004; Tulis, 2013), as well as supportive sentences, similar to the error management messages elaborated by Frese and Keith (2015) or emphasised/discouraging sentences similar to the low-negative feedback of the experiment of Woo et al. (2015). After this first task, students watched a short video about EU institutions. The video had two goals: helping students to revise the information presented during the training questions task; and providing students with a simple and entertaining way to learn more about the topic. It is important to note that the video was not part of the manipulation and was not meant to support learning from errors. After the video, the students were asked to fill in the post-test questions and the manipulation check questions.

At the end of the teaching unit, the students had to create a unique code they communicated the day after to the teacher as proof that they finished the teaching unit. Finally, the students were provided by the teacher with all the information about the research project and they were debriefed.[1]

Materials

[1] To full disclosure, the intervention included another manipulation made salient before the post-test (presence of grading evaluation for the post-test vs. absence of the grading manipulation for the post-test). The manipulation check showed that less than 60% of the sample understood this second manipulation. We checked possible differences in the variables between the students in the grade condition and no grade condition and we did not find any differences. Therefore, we did not consider this manipulation valid.

To assess the variables of the study, the teaching unit included demographic questions, psychometric scales and two performance tests. All the materials and instruments were presented in Italian.

Adaptive Reactions Towards Errors

Students' reactions following errors were measured with the two subscales of the Italian version (Soncini et al., 2022) of the adaptive reactions towards errors scale developed by Dresel and colleagues (2013). The scale consisted of 12 items divided into two dimensions: adaptive affective-motivational reactions (e.g., "While doing the exercise, after an error, I had less motivation to complete the exercise", 5 items); and adaptive action reactions towards errors (e.g., "While doing the exercise, after an error, it was clear that I needed to pay more attention to the next question", 7 items).

Error Beliefs

We used the Italian version (Soncini et al., 2022) of the 5-item scale developed by Tulis and colleagues (2018). The items focus on the importance of making errors for learning (e.g., "I can learn something from my errors″).

Learning Outcomes

Two similar tests based on 7 multiple-choice questions about European Union Institutions were presented to the participants before and after the learning phase of the intervention. The questions were related to the content of the teaching unit, and they were balanced in terms of difficulty and information they asked (i.e., more detailed questions and less detailed questions). The total score was 7 points (1 point for each right answer) for the pre-test and 7 points for the post-test. The two tests were discussed with two middle school teachers and piloted with three middle school students who were not part of the sample of the research. The pre-post test questions are presented in Table S1 in the Supplementary Online Materials.

Manipulation Check

Before finishing the teaching unit, the students were asked to indicate which kind of smiley was presented after each error in the training part. The students could reply by indicating the negative smileys, and the positive smileys or clicking on "I do not remember".

Results

Preliminary Results

As a first step, we checked missing data patterns in the dataset. Little's MCAR test was not significant, χ^2 (67) = 70.12, p = .37, indicating that data were missing completely at random. Second, we calculated Cronbach's alpha, and we created the composite scores for each variable. Descriptive statistics and bivariate correlations of the variables are presented in Table 1. Third, as regards the manipulation check, 106 students out of 126 correctly responded in the supportive feedback condition (7 students replied *I do not remember*, and 13 replied indicating the discouraging smileys). As for the discouraging feedback condition, 113 students out of 124 replied as expected to the manipulation check (6 students replied *I do not remember*, 5 students replied indicating the supporting smileys). Since some students did not reply as expected to the manipulation check, we ran the analyses to test our hypotheses with the whole sample (N = 250) and with a reduced sample including only the students who replied as expected to the manipulation check (N = 219). The results did not change considerably (e.g., $F_{\text{direct effect IV-M1}}$ (6,206) = 11.63, p < .001; $F_{\text{direct effect IV-M1}}$ (6,236) = 12.36, p < .001). Thus, to increase the power of the analyses, we kept the whole sample for the following analyses. Readers can find extensive results on the reduced sample in the Supplementary Online Materials (Tables S2-S3).

Finally, we calculated both correct and incorrect responses provided by students during the manipulation task to ascertain whether participants across different conditions encountered a comparable number of error feedback. In total, the students received 3000 feedback instances (calculated as 250 students multiplied by 12 questions), encompassing feedback for correct answers,

as well as supportive or discouraging error feedback. Regarding incorrect responses, those in the discouraging feedback condition gave 778 incorrect answers, while participants in the counterpart group gave 824 incorrect answers. Conversely, for correct answers, participants in the discouraging feedback condition achieved 710 correct responses, whereas the other group achieved 688 correct responses. We assigned a code of 1 to incorrect responses and 0 to correct responses, subsequently calculating a variable representing the cumulative number of errors made by each student (0 = no errors; 12 = 12 errors/no correct answers). We ran an independent-sample t-test, that showed that the average number of errors made by students in the supportive error feedback condition (M = 6.53, SD = 1.94) was not statistically different from the average number of errors made by students in the discouraging error feedback condition (M = 6.27, SD = 2.18), $t(248) = 1.02$, $p = .16$, *Cohen's* $d = 0.12$. This result, however, does not exclude the possibility that the number of errors affected students' reactions towards errors and their post-test scores, and thus, this variable was used as a control in the analysis.

Table 1

Bivariate Correlations and Descriptive Statistics of the Variables

	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. Error Feedback conditions (0 = Discouraging; 1 = Supportive)	-								
2. AFMOT	.20**	-							
3. AC	.06	.44***	-						
4. Post-test	.03	.04	.01	-					
5. Pre-test	-.02	-.17**	-.07	.18**	-				
6. EB	.01	.31***	.49***	.03	-.06	-			
7. Gender (1 = girls; 2 = boys)	.01	-.04	-.05	.05	.04	.04	-		
8. Age	-.12	-.29***	-.13*	.06	.19**	.03	.03	-	
9. Number of errors	.06	-.07	-.01	-.27***	-.32***	-.01	-.06	.15	-
M	-	3.66	3.75	3.39	3.17	4.04	-	12.18	6.41
(SD)		(.88)	(.77)	(1.63)	(1.48)	(0.62)		(0.88)	(2.06)
Range	-	1-5	1-5	0-7	0-7	1-5	-	11-14	2-11

Kurtosis	-	-.19	.14	-.83	-.45	.10	-	-	-
Skewness	-	-.60	-.63	.14	.28	-.70	-	-	-
α	-	.77	.85	-	-	.72	-	-	-

Note. ** $p < .01$; *** $p < .001$; AFMOT = Affective-motivational reactions to errors; AC = Action reactions towards errors; EB = Error Beliefs; Pre-test = total score to the pretest: Post-test= total score to the postest.

Hypotheses Testing Results

To test our hypotheses, we used the PROCESS 4.2 macro (Hayes, 2022) in SPSS version 26 (IBM Corp, 2019), which allows us to estimate the direct (H1), indirect (H2) effects and the sequential indirect effect (H3) we hypothesised. According to some authors (Hayes, 2009; Rucker et al., 2011), to estimate an indirect effect it is not compulsory to estimate the direct effect between the independent variable and the dependent one (i.e., full meditation model). Since we aimed to test only the indirect effect between error feedback and learning outcomes via the reactions towards errors (i.e., indirect model), we considered the sequential indirect effect (H3) to be valid if the various direct effects (H1 and H2) were significant even in the absence of the direct effect between IV and DV. We set model 6 in the software, and we included the error feedback conditions (supporting vs. discouraging) as the independent variable (X), affective-motivational reactions to errors as the first mediator (M_1), action reactions towards errors as the second mediator (M_2) and post-test results as the dependent variable (Y). Pretest results, error beliefs, number of errors, age and gender were added as control variables.

The results showed that receiving supportive feedback resulted in more adaptive affective-motivational reactions towards errors, supporting H1. In addition, more adaptive affective-motivational reactions resulted in more adaptive action reactions towards errors (Table 2). As expected, our results supported the hypothesis of an indirect effect of receiving supportive feedback on action reactions towards errors, via affective-motivational reactions towards errors (H2), but not

directly, considering the effect of error beliefs on both variables, b = .08, 95%CI [.02; .15][2]. Differently from our expectations (H3), action reactions towards errors were not related to the post-test scores. Moreover, the number of errors was negatively related to the post-test scores, indicating that the fewer errors made during the manipulation task, the higher the post-test scores.

Table 2

Results of the Sequential Mediation Analysis Ran with PROCESS (Model 6; Hayes, 2022)

	AFMOT	**AC**	**Post-test results**
Control Variables	B (S.E.)	B (S.E.)	B (S.E.)
Gender (1 = girls; 2 = boys)	-.07 (.09)	-.07 (.08)	.14 (.21)
Age	-.25 (.06)***	-.06 (.05)	.07 (.12)
EB	.42 (.08)***	.49 (.07)***	.05 (.19)
Pre-test	-.08 (.04)*	.02 (.03)	.13 (.07)
Number of errors	.06 (.03)*	.00 (.02)	-.18 (.05)**
Independent Variables			
Error feedback conditions (0 = Discouraging; 1 = Supportive)	.29 (.09)**	-.01 (.08)	.15 (.21)
AFMOT	/	.28 (.06)***	.10 (.14)
AC	/	/	-.01 (.06)
R^2	.24***	.34***	.09**
F	12.36	17.16	2.92
Effect sizes (d)	0.40[a]	0.12[b]	0.06[3]
Power (1 – β)	0.89	0.15	0.07
Direct effect	/	/	IV- DV -.16 (46; -.26)
Indirect effects	IV- M_1-DV .02 (-.03; .08)	IV- M_2-DV .00 (-.03;.08)	IV- M_1- M_2-DV -.01 (-.02;.02)

[2] This result represents the indirect effect found by analysing the mediation effect (model 4 in PROCESS) of the affective-motivational reactions towards errors on the relationship between the experimental condition and action reactions towards errors. The following control variables were added: age, gender, error beliefs, pre-test results.

Note. ** $p < .01$; *** $p < .001$; EB = error beliefs; AFMOT = affective-motivational reactions towards errors; AC = action reactions towards errors. IV = Independent variable; M_1 = First mediator (Affective-motivational reactions); M_2 = Second mediator (Action reactions); DV = Dependent variable (Learning outcomes). [a] small-medium effect; [b] small effect; [3] no effect (Cohen, 1988).

Discussion

The present study sought to experimentally test whether receiving supportive feedback after an error increases students' adaptive affective-motivational reactions towards errors (H1), which, in turn, are related to more adaptive action reactions towards errors (H2), which in turn promotes higher learning outcomes (H3). To do so, a targeted intervention was carried out with Italian middle school students who filled in an online teaching unit about European Union Institutions. The emotional facet of error feedback received during the task was manipulated, and students received either supportive error feedback (smiling smileys and encouraging sentences) or discouraging error feedback (disappointing smileys and error-emphasising sentences) after every error made during the learning phase of the teaching unit (See Appendix 1). After the manipulation, the students reported their reactions towards errors (affective-motivational and action reactions) and completed a post-test on the topic of the teaching unit to assess their learning outcomes.

The primary contribution of this study pertains to the effects of the manipulation on students' affective-motivational reactions towards errors. Our findings indicate that providing students with supportive error feedback led to a notable increase in their affective-motivational reactions towards errors. Significantly, this effect persisted even after accounting for various variables, such as error beliefs and the number of errors committed during the manipulation task. Aligning with the learning from errors model (Tulis et al., 2016), this finding provides substantive support for the causal connection between error feedback and the subsequent emotional regulation, and motivational adjustments in students after making errors. Moreover, unlike previous correlational studies relying on students' perceptions of the error classroom climate (Soncini et al.,

2022; Grassinger et al., 2018), our study is grounded in the actual feedback received following an error.

As for literature on error feedback, our results underscore that the mere provision of minimal error feedback, containing information solely on whether the response is corrected or not, fosters more adaptive affective-motivational reactions. This finding enriches the ongoing discussion on the crucial role of the emotional component of error feedback, previously manipulated by Woo et al. (2015), offering new perspectives. Indeed, our results indicate that the emotional facet (supportive vs. discouraging) of error feedback significantly influenced the emotions and motivation of students following errors, even when adjusting for error beliefs and the number of errors made during the task. This finding adds evidence to the literature on error feedback in error-centred learning models (e.g., Frese & Keith, 2015; Metcalfe, 2017), and contributes to the debate on which kind of feedback should be provided to students to maintain high motivation and positive emotions in facing errors consequences (Keith et al., 2022), and is in line with findings on teachers' error-handling strategies (Tulis, 2013).

As for the negative significant association between age and affective-motivational reactions towards errors, this result is in line with previous findings about academic motivation and achievement emotions. Indeed, it has been extensively shown that academic motivation tends to decrease with the increase in the age of the students (e.g., Gnambs & Hanfstingl, 2016). Along the same line, research on achievement emotions (e.g., Pekrun, 2006) demonstrated that activating-positive emotions, such as enjoyment, tend to decrease throughout the school years, whereas deactivating and avoidant-coping-related emotions, such as boredom, increase (e.g., Vierhaus et al., 2016).

The second contribution of the study concerns the mediation effect of error feedback on adaptive action reactions, via affective-motivational reactions. Although this result is merely correlational because we did not expect nor find effects in action reactions towards errors due to the

manipulation, it is in line with previous results (Grassinger et al., 2018; Soncini et al., 2022) and the theoretical model proposed by Tulis and colleagues (2016).

The third contribution pertains to the only significant effect on the post-test scores. Indeed, contrary to our expectations, our experimental study did not support the indirect relationship between receiving supportive error feedback and learning outcomes. We based this hypothesis on previous correlational studies (Soncini et al., 2022; Grassinger et al., 2018) that found a significant indirect effect of students' perceptions of positive classroom climate on better learning outcomes, via adaptive reactions towards errors. According to our results, however, neither supportive feedback nor the two adaptive reactions towards errors related to better post-test scores. Possible explanations may lay on the kind of feedback we used in the manipulation, the duration of the manipulation and the assessment of action reactions. Minimal feedback, like the one used in the manipulation, has been found to not be so effective for increasing learning and students tend to learn more when they are provided with corrective feedback (Kim et al., 2018) or when they can process and elaborate the errors like in the error-centered learning interventions (Kapur, 2014; Lee, 2020). Furthermore, interventions are often designed with a longitudinal time frame, while in this case, students did not have time to elaborate on the errors. Finally, the measure of action reactions towards errors might not be appropriate to understand the actual actions students might have wanted to implement to learn from the errors. Indeed, the scale used represents more the intentions to do something after the error, rather than the actions effectively implemented.

Although the hypothesised indirect effect was not confirmed, the number of errors made during the manipulation was negatively related to post-test scores. This result is in line with recent studies showing that success feedback led to better learning outcomes than error feedback (Eskreis-Winkler & Fishback 2019; Keith et al., 2022), reopening the debate on whether failure and errors increase learning more than correct responses. In this sense, our finding supports the idea that students who made fewer errors performed better in the post-test, regardless of the error feedback

they received (see results of t-test in Preliminary results section), and their pre-test scores (see Table 2).

Taken together, our results suggest potential directions on how to create teaching units based on supportive error feedback that helps to detect errors in a positive way, which is essential to promote adaptive emotional and motivational regulation, which is in turn related to students' intentions to overcome the error. In addition, the intervention was implemented completely online. This is an innovative aspect in the body of research based on the learning from errors process (Tulis et al., 2016), which has focused more on in-person learning dynamics (e.g., Soncini et al., 2021; Soncini et al., 2022; Steuer et al., 2013; Tulis, 2013). Finally, the unexpected relation between the number of errors and post-test scores adds evidence to the debate opened by the study of Eskreis-Winkler and Fishback (2019) on the value of making errors for learning.

The present study has limitations that should be mentioned. Firstly, the lack of a neutral condition did not allow us to test the differences between receiving supportive error feedback and receiving no feedback at all, which may have reinforced our conclusions. In addition, although the online nature of the experiment is a strength of the study, it must be acknowledged that it was not possible to know the conditions under which the students filled in the teaching unit (e.g., alone or with others; in contexts where they could concentrate or not, etc...), and thus we could not control possible interfering variables. Furthermore, in this study, we included variables related to the conceptual framework of the learning from errors model (Tulis et al., 2016), but other individual and contextual variables we did not consider may intervene in the learning from errors process. For instance, causal attribution (Grassinger & Dresel, 2017), and incentives to not err (Frese & Keith, 2015) are important variables to consider. Finally, the experimental design presents some limitations. Indeed, the error feedback showed after errors were minimal feedback that did not provide information about the correct answer. It would have been important to compare minimal feedback with informative feedback to detect differences between the two. In addition, we did not include in the manipulation either an actual concrete consequence after making errors, excluding the

threat of loss typically associated with the errors (Keith et al., 2022), or an activity/moment where students could elaborate on the errors. Furthermore, we did not measure actual students' behaviour after errors, and we did not use objective measures of emotional-motivational changes.

Conclusions

By simulating the affective and cognitive responses to errors that the teacher can provide to students in an in-presence context (Tulis, 2013), the results of this targeted intervention showed that receiving supportive error feedback helps to promote students' positive approach to errors in an online learning context. This finding is important and timely because it enriches the literature with new evidence on how to structure error-friendly online teaching units during the post-COVID-19 era where school digitalisation and the development of digital learning tools are key factors for the development of education systems (European Commission, 2021; OECD, 2020).

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