

# Effects of Timing and Reference Frame of Feedback: Evidence from a Field Experiment\*

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## Abstract

Information about past performance has been found to sometimes improve and sometimes worsen subsequent performance. Two factors may help to explain this puzzle: which aspect of one's past performance the information refers to and when it is revealed. In a field experiment, students received information about their absolute rank in the last math exam (level feedback), their change in ranks between the second last and the last math exam (change feedback), or no feedback. Feedback was given either 1-3 days (early) or immediately (late) before the final math exam of the semester. Both level feedback and change feedback significantly improve students' grades in the final exam when given early and tend to worsen them when given late. The largest effects are found for negative change feedback and are concentrated on male students, who adjust their ability beliefs downwards in response to feedback.

**Keywords:** timing of feedback, change and level feedback, motivation, field experiment

**JEL Codes:** I21, M54, D91

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# 1 Introduction

Students and employees are often given feedback about their past performance with the intention to positively influence their future performance. Feedback has indeed sometimes been found to improve performance (Azmat and Iriberry, 2010; Blanes i Vidal and Nossol, 2011; Tran and Zeckhauser, 2012)<sup>1</sup> and may have advantages over monetary incentives as it can be used when the latter are difficult to implement or not socially accepted. However, feedback is also frequently found to backfire (Barankay, 2012; Ashraf et al., 2014; Azmat et al., 2018; Bradler et al., 2016a) or to be ineffective (Eriksson et al., 2009).<sup>2</sup> Asking which factors are crucial for its success is therefore important.

The influence of a small number of factors on the effectiveness of feedback has already been investigated. For example, the motivational power of feedback depends on whether a pay-for-performance or a flat incentive scheme is present (Azmat and Iriberry, 2016), or whether the information provided is sufficiently precise (Hannan et al., 2008). Furthermore, relative feedback tends to be more effective than performance information referring to an absolute standard (Azmat and Iriberry, 2010). At the same time, there is inconclusive evidence about whether rank information given in public or private is more effective (Gill et al., 2016; Bursztyn and Jensen, 2015; Ashraf et al., 2014; Hannan et al., 2013; Tafkov, 2013; Tran and Zeckhauser, 2012).<sup>3</sup> Besides these findings, the question of what makes feedback effective has received rather little attention, leaving many important aspects that could be relevant for its success as a motivational tool unstudied. We begin to fill this gap by asking whether the reference frame—feedback may compare people in terms of their performance *levels* or their performance *changes*—and the timing of relative feedback influence its effectiveness. These seem to be important questions as one would expect both dimensions to matter for people’s motivation, and insights into their role can potentially be easily incorporated into practice.

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<sup>1</sup>Economists have investigated different kinds of feedback, such as process feedback (by allowing subjects to observe the behaviors of other people performing the same task, see e.g. Falk and Ichino, 2006; Mas and Moretti, 2009) or outcome feedback (by providing a quantitative measure of past performance such as a test score or rank, see e.g. Tran and Zeckhauser, 2012; Azmat et al., 2018). We will focus on outcome feedback in this study.

<sup>2</sup>See also Kluger and DeNisi (1998) for evidence from the psychological literature.

<sup>3</sup>See also Dechenaux et al. (2015) for a summary of the findings in the tournament literature.

In this paper, we study a field experiment in secondary school classes in which we exogenously vary *whether* students receive private rank feedback, *when* they receive it and *what* its standard of comparison (reference frame) is.<sup>4</sup> Within classes, we varied the type of private written feedback students aged around 11-12 years received from their teachers. It either contained information about (i) the absolute rank in the last math exam (level feedback), (ii) the change in ranks between the two previous math exams (change feedback), or (iii) no information (control). Random allocation of students into treatments within classes allows us to control for heterogeneity of the class environments and to identify the effects of feedback based on comparing students within the same class. Across classes, we varied whether students received their feedback (a) 1-3 days, or (b) immediately, i.e. a few minutes, before the final math exam of the semester. This exam involves high stakes for the students as mathematics is a core subject of the curriculum and students write only three exams per semester in total.<sup>5</sup>

We find (i) that timing of feedback is very important, and (ii) similar effects for both feedback types. Feedback given early tends to increase performance while the same feedback given late tends to decrease it. When given a few days before the exam, both change and level feedback significantly increase subsequent performance. In classes with early feedback, students receiving feedback about their rank level significantly increase their performance by 0.2 grade points<sup>6</sup> (3.9 percentage points) compared to students receiving no feedback, while students receiving feedback about rank changes significantly increase their performance by 0.3 grade points (3.8 percentage points). We find it to be particularly beneficial to inform students who became worse about their negative change in performance a few days before the exam as this significantly improves these students' outcomes by 0.6 grade points (8.1 percentage points). In contrast, any feedback given to students immediately before the exam tends to lower subsequent performance. In

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<sup>4</sup>A model that motivates the treatment variation (and builds on Fischer and Sliwka, 2018) is presented in the Online Appendix.

<sup>5</sup>Students need an average grade of 3 (on a scale from 1, highest, to 6, lowest) in all subjects for being promoted to the next grade. There are three core subjects—Math, German and English. If students get the grade 4 in one core subject, they can only compensate this grade by a good performance (grade 2) in another core subject (low performance in core subjects cannot be compensated by good performance in minor subjects).

<sup>6</sup>Grades are given on a 6 point scale where 1 is the highest and 6 is the lowest grade.

particular, informing students who became worse about their negative change in performance immediately before the exam decreases these students' exam grades significantly by 0.3 grade points. Moreover, we find heterogeneous gender effects: While male students respond very strongly to feedback, female students largely do not seem to be affected.

To shed light on the psychological mechanisms that could drive the effects of feedback on performance, we elicit students' confidence in their math ability (belief in competence level in math), their effort-effectiveness belief (perceived relationship between effort and academic outcome) and their state self-esteem (current perception of self-worth and general competence) after the intervention. The analysis shows that male students negatively update their beliefs while girls tend to positively update their beliefs in response to feedback. This may explain why the effects of feedback on performance are largely driven by male students and highlights the importance of information processing and belief elicitation for understanding the effects of feedback on behavior.

To our knowledge, this is the first study identifying causal effects of timing of feedback and the first to compare the causal effects of two generic types of feedback (level feedback versus change feedback). Our results are relevant for educators because feedback is one of the most important factors related to student achievement (Hattie, 2015), and used almost daily by teachers (by means of grades or individual talks).<sup>7</sup> Therefore, our findings—on how to time feedback and which reference frame of comparison to choose—give guidance for the design of feedback provision to students. Moreover, the general findings have important implications for other settings, i.e. the workplace. Employees working on a task over several periods might be interested and more motivated to learn whether they improved performance than to learn the level of their past evaluation and managers might want to know how best to time employee feedback.

The paper is organized as follows. The next section gives an overview of the related literature. In section 3 we motivate the treatment variation and report the results of a survey conducted prior to the experiment, in which we test whether students of our target age group understand and how they perceive the two types of feedback. Section 4

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<sup>7</sup>See also <https://visible-learning.org/hattie-ranking-influences-effect-sizes-learning-achievement/> for an updated list of factors related to student outcomes.

describes our experimental procedure. Section 5 presents the results and investigates potential psychological mechanisms. Section 6 concludes.

## 2 Related Literature

Economists traditionally focus on the introduction of incentives to raise performance but field experiments on monetary and non-monetary (Angrist and Lavy, 2009; Kremer et al., 2009; Fryer, 2013; Bettinger, 2012; Fryer et al., 2012; Levitt et al., 2016) incentives for teachers and/or students in recent years have produced mixed results.<sup>8</sup>

Few studies so far have investigated the effectiveness of feedback to increase performance in the context of education and those we are aware of, have primarily relied on university student samples (exceptions are Azmat and Iriberry, 2010, and Goulas and Megalokonomou, 2015).<sup>9</sup> Tran and Zeckhauser (2012) provide Vietnamese students participating in an experiment involving an English test either with private feedback or private plus public feedback about their ranking in in-course mock exams.<sup>10</sup> Overall, the authors find a positive effect of feedback on the final English test and that private plus public feedback tends to outperform private feedback only. This difference, however, was only marginally significant.<sup>11</sup> A more recent study by Bandiera et al. (2015) exploits data of a natural experiment in the UK where some university students were provided with private, absolute feedback on their past exam performance and others were not. Feedback on exam performance improved future performance mostly for more able students and for students who initially had less information about the academic environment. Azmat et al. (2018) provide college students with feedback on their position in the grade distribution every six months over a period of three years. They find that students who

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<sup>8</sup>Surprisingly little of the large heterogeneity of teacher effectiveness can be explained by observable teacher characteristics (Hanushek and Rivkin, 2006), which makes it difficult to improve educational outcomes by screening for good teachers.

<sup>9</sup>Damgaard and Nielsen (2018) recently review the use of feedback and other behaviorally motivated interventions in education.

<sup>10</sup>Private feedback was given by phone and public feedback by postings on the university's noticeboard and website.

<sup>11</sup>In contrast to Tran and Zeckhauser (2012), the results by Ashraf et al. (2014), a study outside the educational context, reveal that private plus public feedback reduces performance of health workers in Zambia in a nationwide training program.

received feedback suffered a decrease in their performance relative to a control group. This effect is driven by students who underestimated their relative performance in the absence of feedback. In contrast, Brade et al. (2018) give first-year university students in Germany (normatively framed) relative performance feedback about their accumulated course credits and find an increase in performance only when the feedback is positive.

There is little evidence on the effects of feedback on school aged children (Azmat and Iriberry, 2010; Goulas and Megalokonomou, 2015; Hermes et al., 2018)<sup>12</sup>, although schools are a natural setting in which feedback is given almost daily and in which feedback has a potentially large impact on individuals.<sup>13</sup> Azmat and Iriberry (2010) study the motivational effect of relative performance feedback among high school students in Spain (aged 14 - 18) in a natural field experiment. For one school year, a high school in the Basque Country adopted a new system of producing report cards providing students with information on whether they were performing above or below the class average as well as the distance from this average. Before and after this change, report cards informed students only about their own grade point average. The new relative performance feedback had positive effects and increased students' grades by 5 %. However, the effect disappeared as soon as the information was removed. Goulas and Megalokonomou (2015) also exploit data of a natural experiment in high schools in Greece. Similar to Azmat and Iriberry (2010), information about students' performance was public in some years and—due to a policy reform—private information in other years. In the feedback condition, student's performance was publicly announced giving students the opportunity to calculate their national and school rank. In contrast to Azmat and Iriberry (2010), the authors find a positive effect of feedback for the better students. Hermes et al. (2018) study performance transparency in a mathematics e-learning applications in a primary school setting. The authors compare a public performance ranking to a private individual feedback. While

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<sup>12</sup>Bursztyn and Jensen (2015) also study feedback on school aged children (high school). The top three performers of a class were publicly announced on a leader board. Hence, children not among the top three performers did not get information about their rank, but only new that their rank below the third rank.

<sup>13</sup>In a field experiment in a Dutch school for intermediate vocational education, Buurman et al. (2018) investigate the effect of feedback given by students to teachers on student evaluation scores. They find a zero average treatment effect, but teachers receiving a negative feedback (students' evaluation is lower than teachers' self-assessment) improve significantly in response to receiving feedback.

transparency has overall no effects on performance in math, low-performers tend to do better and to display higher motivation in the public feedback condition.

We are not aware of any studies who investigate the effects of timing and social reference frame of feedback. We chose to provide students with relative performance information (the rank within their class) as people are strongly motivated by it, even in the absence of any tangible benefits (Charness and Rabin, 2002; Azmat and Iriberry, 2010; Kuziemko et al., 2014; Gill et al., 2016). In particular, we either provide students with information on the level of their rank or their change in ranks. It is interesting to study the effects of feedback about how one’s performance has changed in the past because it may help to promote the belief that skills can be developed by exerting effort (also called a “growth mindset” in the psychological literature [see O’Rourke et al., 2014; Paunesku et al., 2015], which is closely related to the concept of “grit”, recently investigated by Alan et al., 2016). We compare change feedback to level feedback as there is evidence in the literature that feedback comparing performance levels is often positively motivating, because it may help to correct people’s overconfidence with respect to their performance level (Krueger and Mueller, 2002; Hoelzl and Rustichini, 2005; Malmendier and Tate, 2005; Park and Santos-Pinto, 2010), and thus makes them less confident in already having done “enough” (Azmat et al., 2018; Fischer and Sliwka, 2018). However, when there is large heterogeneity among performance levels, revealing information about them may reduce performance (Gürtler and Harbring, 2010). Feedback that compares students not in terms of their levels but in terms of their changes in performance may alleviate this problem while possibly maintaining the motivational effects of social comparison.

Timing is potentially crucial for the effects of feedback because outcomes in the workplace or educational settings may be influenced by effort exerted at different times—on preparation and at the task itself (cf. Levitt et al., 2016; Wagner, 2016 for changes in effort at the task itself). While earlier feedback may influence preparation effort, possibly by countering students’ tendency to procrastinate and to start preparations too late (Steel, 2007), feedback given more immediately before a task may potentially have a stronger effect on effort at the task itself due to people’s tendency to place a greater weight on more

recent information (Hogarth and Einhorn, 1992). Furthermore, timing of feedback may also matter if it influences both performance expectations and emotions (Loewenstein, 2000; Lane et al., 2005; Kräkel, 2008; Bradler et al., 2016b) and the latter might have stronger effects on motivation in the short run than in the long run (Lempert and Phelps, 2014). For example, someone who learns that his past performance is worse than expected may realize that he has to work harder to attain his desired outcome. However, having this overconfidence corrected may involve (temporary) negative emotions that decrease the enjoyment of a task or distract from it (Benabou and Tirole, 2016) and may thus decrease performance in the short run.<sup>14</sup>

### 3 Motivation and Pre-test of Treatments

#### 3.1 Motivation of Treatments

We varied the type of feedback as we expected that feedback about levels influences students empirical beliefs in different ways than feedback about changes. Building on a model by Fischer and Sliwka (2018) two types of beliefs might matter for how much effort a student invests in the exam, (i) confidence in her past level of math performance and (ii) confidence in the effectiveness of her effort (i.e. her ability to improve her math performance). In the online appendix, we present an application of the model to our setting. Assuming that students at different parts of the ability distribution each strive for exam outcomes within their reach, the model predicts that increasing a student's confidence in her past level of math performance decreases the perceived necessity to invest additional effort in exam preparation to reach the desired outcome in the next exam. Furthermore, according to this model, confidence in the effectiveness of effort reduces a person's perceived effort costs. Thus, raising confidence in the effectiveness of effort increases effort. Fischer and Sliwka (2018) find evidence that people's effort in a lab experiment responds as predicted by their model.

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<sup>14</sup>The importance of timing is also supported by the dual-process theory (Loewenstein, 2000; Alos-Ferrer and Strack, 2014): People's immediate "hot state" response to information differs from their longer term "cold state" response.

In our classroom setting, we expect that the effect of feedback about one's level of past performance depends on whether a person ex-ante is overconfident or underconfident with respect to her level of past performance. If she is overconfident, learning about the true level of past performance is disappointing and thus will lower her confidence in her level of performance (and increase the perceived necessity of effort), if she is underconfident, learning the same information will be positively surprising and raise her confidence in her level of performance (and decrease the perceived necessity of effort). Likewise, the effect of feedback about one's changes in performance depends on how it affects a person's beliefs. The psychological literature on the growth mindset argues that making (negative or positive) changes in past performance salient strengthens confidence that one's outcomes can be influenced by one's effort, i.e. confidence in the effectiveness of effort (which increases effort). Therefore, based on the model of Fischer and Sliwka (2018) and the psychological literature we expect that the two feedback types affect student's performance in different ways if students are on average overconfident.

We varied the timing of feedback as psychologists, and in recent years also economists, consider the role of emotions in decision making. We suppose that emotions, besides information processing, may mediate the effort response to feedback. Disappointing feedback likely worsens a person's emotional state, which may decrease the enjoyment of a given task and effort (Lane et al., 2005; Benabou and Tirole, 2016). Emotions are generally considered to be short lived (Lempert and Phelps, 2014). For this reason the short-run response to feedback may differ from the longer-run response (Loewenstein, 2000; Alos-Ferrer and Strack, 2014), which implies that the timing of feedback may be relevant for the observed response. While we expect the longer-run behavior to be driven by the rational response to new performance information, the short-run response should be driven by a combination of rational and emotional response. For example, in the short run disappointing performance feedback raises the necessity to exert more effort (strengthening extrinsic motivation) but may at the same time worsen the emotional state (weakening intrinsic motivation). Thus while disappointing information likely increases effort in the longer run, the emotional response attenuates the incentive effect and may even dominate

it in the short run.

### 3.2 Pre-test of Treatments

Students in our sample are young and in order to test whether they understand our feedback (to disentangle lack of understanding and ineffectiveness of the information) and how they interpret it (to enable us to interpret possible treatment effects), we conducted a survey in 6 classes in 4 schools with a total of 151 students of the same age group as our experimental sample before implementing the field experiment. These children did not participate in the main experiment.

The survey consisted of a two-page questionnaire. On the front of the page students saw a feedback note (of the same types we later used in the experiment) addressing a fictitious student named “Paul” and were asked to imagine themselves in his position. The feedback note contained either level or change feedback, and both of them were varied (good ranks to bad ranks, positive and negative change in ranks). On the back of the page, students had to shortly summarize the information on the front of the page and answered a quiz to test whether they understood it correctly. They were also asked to give their guess of how Paul feels (“very good” to “very bad”) after having read the feedback note and of how motivated (“not at all” to “very strongly”) Paul will be to exert effort in the next exam. We also asked students whether they knew the number of children in their class, which is crucial for correctly interpreting rank feedback.

Most students correctly understood the feedback notes. 85.56% of the students could correctly calculate by how much Paul’s rank changed and 94.74% could correctly determine the position of Paul’s rank when given level feedback. Moreover, 86.09% of students know the exact size of their class. The mean responses to the questions concerning Paul’s emotions and motivation are presented in Figure A.1 in Appendix A.<sup>15</sup> Students believe that bad feedback (negative change in ranks or rank level below median) makes a student feel worse than good feedback but that the student’s motivation to exert effort is quite

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<sup>15</sup>The results indicate that students believe that Paul would be more motivated when receiving change feedback than when receiving level feedback while they do not indicate that the two feedback types affect emotions differently. Note that the difference in reported motivation between the change feedback and the level feedback may be driven by the chosen ranks.

high (above 3 on a 5 point scale) and approximately the same with negative and positive feedback.

Overall, the results of the pre-experimental survey indicate that most students of our target age group correctly understand the information contained in two types of feedback and that they perceive their content as affecting emotions but do not believe that more negative feedback will generally be less motivating than more positive feedback.

## 4 Timeline of the Experiment

The experiment was conducted in 19 classes (grades 5 and 6) in 7 secondary schools in Germany<sup>16</sup> and was approved by the ethics committee of the University of Düsseldorf. 352 students received parents' consent (on average 73.9% per class) and participated in the experiment during May and June 2016. Researchers were never present in the classroom to maintain a natural examination situation and the feedback was given to students by their math teacher to maximize its credibility.<sup>17</sup> To train teachers how to conduct the experiment, we visited the schools in the run-up of the experiment. During this meeting, the intervention was explained and teachers' questions were answered. We sent teachers two envelopes with material needed to run the experiment. A first envelope contained written teacher instructions outlining the time schedule and steps of the intervention, consent forms to be signed by parents and templates (to be returned to researchers) for providing results of the first and the second math exams of the semester (grades and points obtained in each exam and the maximum number of points reachable). Teachers provided us with names, enabling us to print personalized feedback notes by calculating students' ranks in the last math exam and their change in ranks from the second last to the last math exam. A second envelope was sent to schools a few days before the third exam. It contained the personalized feedback notes, which were sheets of paper that were folded and had the name of the student it referred to clearly written on its outside. The envelope also contained a result template for the third exam and student questionnaires.

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<sup>16</sup>Schools are located in the cities of Bonn, Cologne, and Düsseldorf.

<sup>17</sup>The credibility of the source has a substantial effect on how feedback is interpreted. Ilgen et al. (1979) identified two components of source credibility: expertise and trustworthiness.

## Treatment Intervention

We want to test how relative performance feedback affects a student’s performance in a high-stakes math exam.<sup>18</sup> Based on a 2 X 3 design, we vary both the *timing* of feedback and the *reference frame* of feedback independently.

The timing of feedback was randomized at the class level. Students either received feedback 1-3 days before the exam (EARLY TIMING) or immediately before the exam sheets were handed out (LATE TIMING). This treatment design allows us to investigate whether the timing of feedback matters for exam performance. The reference frame of feedback was randomized at the student level. Within the same class, students with parents’ permission to participate received personalized written feedback about their rank level in the last math exam (LEVEL FEEDBACK), about their change in rank between the second last and the last math exam (CHANGE FEEDBACK), or a personalized note that only wished them good luck (CONTROL). In all treatments, teachers gave a folded feedback note to each student that had the student’s name written on its outside. To personalize the feedback, the note addressed the student by their first name and was signed with the teacher’s name. While students in CONTROL received no information about their past performance, in CHANGE FEEDBACK, students received information about their change in rank but no information on their absolute rank levels.<sup>19</sup> Students in LEVEL FEEDBACK were informed about their relative rank in the last exam but received no information on their performance in the second last exam or about how their performance changed. As students had received their grades in the last two exams after the teachers had graded them (i.e. approximately 2 and 4 months before the last exams, respectively), the feedback information served as a reminder that contained more detailed information about different aspects of their relative performance and made different aspects of comparison salient.

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<sup>18</sup>Providing rank feedback seems promising in light of recent findings that a student’s rank within their class or cohort affects later achievement independently of underlying ability (Murphy and Weinhardt, 2014; Elsner and Isphording, 2017). Murphy and Weinhardt (2014) find that students with a one standard deviation higher rank in primary school will score 0.08 standard deviations better at age 14 and Elsner and Isphording (2017) find that high school students with a higher rank have higher expectations about their future career outcomes, are more optimistic and self-confident and, indeed, have a higher likelihood of going to college.

<sup>19</sup>See Appendix B for an English translations of the exact wording and layout of the notes.

To shed light on the channels through which feedback might change students' learning and exam performance, students had to answer a questionnaire after reading the feedback notes (in EARLY TIMING) or after completing the exam (in LATE TIMING).<sup>20</sup> The questionnaire elicited students' confidence in their mathematics ability, their effort-effectiveness belief, and their state self-esteem to allow us to explore mechanisms as well as gender, character traits, and demographic information to allow us to explore possible heterogeneities in treatment effects (Ilgen et al., 1979; Lam and Schaubroeck, 2000; Noe, 2000; Fedor et al., 2001; Buser and Yuan, 2016). Confidence in math ability was elicited using the German version of the math efficacy scale included in the OECD's Programme for International Student Assessment (PISA) studies (OECD, 2014; based on Bandura, 1986). To elicit students' effort-effectiveness belief, we asked them how much they believe their exam outcomes can be affected by their effort. State self-esteem was measured using the Rosenberg self-esteem scale (Rosenberg, 1965; German version by von Collani and Herzberg, 2003). Character traits were also elicited with validated scales and included (i) locus of control (adapted from PISA (OECD, 2014); based on Rotter, 1966), (ii) competitiveness (adapted from PISA (OECD, 2014); based on Owens and Barnes, 1992), and (iii) perseverance (adapted from PISA (OECD, 2014); see OECD, 2013 ).<sup>21</sup>

After students filled in the questionnaires, teachers collected them, while students were required to crumble the feedback notes and to throw them in a garbage bin.<sup>22</sup> Upon sending the results of the final exam as well as the filled-in questionnaires, teachers were asked to fill in a short survey.

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<sup>20</sup>In EARLY TIMING, students filled in the questionnaire immediately after receiving the feedback notes, while in LATE TIMING students could only fill in the questionnaire after completing the exam. Furthermore, due to time constraints, in LATE TIMING, the questionnaire was shorter and contained only some of the scales, of which most only consisted of a subset of items as compared to validated versions used in the EARLY TIMING questionnaire and were included for exploratory reasons. Our main analyses of the psychological mechanisms will therefore be based on the validated scales filled in by students immediately after receiving feedback in EARLY TIMING classes.

<sup>21</sup>For the measures adapted from the PISA studies also see Marsh et al. (2006).

<sup>22</sup>This was to prevent the feedback notes from being shown to other students (with EARLY TIMING) and from teachers finding them in the exam booklets when they graded the exams (with LATE TIMING).

## 5 Results

This section presents the results and is organized as follows: First, we describe our randomization strategy and discuss concerns about non-random self-selection into treatment groups. Thereafter, we present our data and descriptive statistics before analyzing the impact of feedback on students' performance. We first investigate the effects of timing and then of the reference frame of feedback. Additionally, we explore psychological mechanisms by which feedback affects outcomes.

### 5.1 Randomization

Blocked on grade level, classes were randomized into either the EARLY TIMING treatment or the LATE TIMING treatment. With respect to these class-level treatments non-random self-selection was possible as parents learned whether feedback would be given 1-3 days before the exam or immediately before the exam. This was necessary to receive parents' fully informed consent. However, as we will show, we do not find evidence for strategic self-selected into class-level treatments. Within classes, students were then randomized into the CONTROL group, CHANGE FEEDBACK treatment or LEVEL FEEDBACK treatment. Parents did not learn to which of the three treatments their child was assigned as randomization into student-level treatments took place only after we obtained parents' consent and students only learned it when they received their feedback notes. Hence, non-random self-selection into the student-level treatments was not possible. We chose to give feedback in the subject mathematics to minimize the possibility of grade manipulation by teachers. Teachers' discretion in grading is expected to be very small in mathematics compared to a subject where students have to give verbal answers.

Overall, randomization for both class-level and student-level treatments was successful as we find no significant differences between treatments in any relevant dimension (prior test scores and grades, gender, student demographics). Table C.1 in Appendix C reports differences between EARLY TIMING and LATE TIMING. Student and teacher observables do not differ significantly between these class-level treatments, except with respect to the share of students per class who participated. Surprisingly, the share of participants

turned out to be significantly lower in the EARLY TIMING treatment as compared to the LATE TIMING treatment. We expected the opposite as parents might be more concerned about possible (negative) effects on exam outcomes of their children when feedback is given shortly before the exam.<sup>23</sup> This could be an indication that parents were not concerned about the timing of the feedback and that the difference in participation rates is just a coincidence, in particular because all relevant characteristics are balanced. Moreover, our analysis controls for teacher grading by accounting for prior test scores and by standardizing test scores on class level.

Randomization checks for student-level treatments (CHANGE FEEDBACK, LEVEL FEEDBACK, CONTROL) can be found in Table C.2 and Table C.3 in Appendix C. Self-selection into these treatments was not possible, as students had no information on assignment prior to the intervention, and student observables in the student-level treatments are not significantly different from each other.

To summarize, a lower proportion of students participate in the EARLY TIMING treatment. However, student characteristics and prior performance measures do not differ significantly between the class-level and the student-level treatments.

## 5.2 Data and Descriptive Statistics

Our data consist of pre and post intervention performance measures provided by the teachers as well as demographic information and psychological scales from student questionnaires. Importantly, we have detailed information on students' past performance as we know their grades and points in the two last exams before the intervention (written several months earlier) as well as the maximum score possible in these exams.<sup>24</sup> Students are on average 11.60 years old and have 1.33 siblings. 46.42% of the students are female and 38.04% of students have a non-German first and family name, hinting at a recent migration experience in their family. Our sample seems to be reasonably representative for secondary school students in the German federal state in which our experimental schools

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<sup>23</sup>Overall, 26.1% students did not get their parents' consent to participate in the experiment (22.5% in the LATE TIMING treatment and 29.7% in the EARLY TIMING treatment).

<sup>24</sup>See Figures H.1 - H.3 in Online Appendix H for the distribution of points in all three exams.

are located (North Rhine-Westphalia), as overall 50.81% of secondary school students are female and 41,45% have a migration background.<sup>25</sup> The average grade is 2.74 in exam 1 and 2.59 in exam 2 on a scale from 1 to 6, where 1 is the highest and 6 is the lowest grade.<sup>26</sup> Table 1 presents the number of observations for each treatment cell and summarizes the feedback students received by treatment. It reveals that the range and standard deviation of feedback received in the CHANGE FEEDBACK and LEVEL FEEDBACK treatments are of similar magnitude. Figures D.1 and D.2 in Appendix E show the distribution of feedback pooled over class-level treatments.

Table 1: Descriptive statistics of provided feedback

		Obs.	Mean	Std. Dev	Min.	Max.
Change Feedback	Early Timing	59	0.763	8.052	-21	+21
	Late Timing	57	0.842	8.239	-19	+19
Level Feedback	Early Timing	64	13.922	8.407	1	30
	Late Timing	60	13.233	8.208	1	30
Control	Early Timing	55	-	-	-	-
	Late Timing	55	-	-	-	-

*Note:* This table presents descriptive statistics of the feedback given to students by class-level and student-level treatments.

### 5.3 Effects of Feedback on Performance

In the following we investigate the effects of our intervention. The following tables present results from linear regressions (OLS) that include prior performance as linear control variables and student characteristics as dummy variables, as well as a constant. Furthermore, regressions analyzing treatments that were randomized at student level contain class fixed effects and regressions analyzing treatments randomized at class level contain school fixed effects. The advantage of including class (school) fixed effects is that we can control for heterogeneity of the class (school) environments and the identified effects of feedback are based on comparing students within the same class (school). For all presented results, the

<sup>25</sup><https://www.schulministerium.nrw.de/docs/bp/Ministerium/Service/Schulstatistik/Amtliche-Schuldaten/StatTelegramm2016.pdf>

<sup>26</sup>Translation of German grades to American grades: 1.0=A+ or A; 1.3=A-; 1.7=B+, 2.0=B; 2.3=B-; 2.7=C+; 3.0=C; 3.3=C-; 3.7=D+; 4.0=D; >4.0=F (cf. <http://german.princeton.edu/wp-content/uploads/2014/11/GPA-Conversion-Chart.pdf>).

reported standard errors are clustered at the class level and corrected using bias-reduced linearization (Bell and McCaffrey, 2002; Angrist and Pischke, 2008; Cameron et al., 2008; Cameron and Miller, 2015) to allow for cluster-robust inference with a small number of clusters.

First, we study the effect of *timing* of feedback on performance to learn whether students receiving the intervention 1-3 days before the exam had different outcomes than students receiving the intervention immediately before the exam. Then, we will look at the EARLY TIMING and the LATE TIMING groups separately to study the effect of *reference frame* of feedback. This will allow us to explain whether a possible difference between the EARLY TIMING and the LATE TIMING groups is driven by the effects of the CHANGE FEEDBACK, or the LEVEL FEEDBACK, or both.

### The Role of Timing of Feedback

We first analyze the effect of feedback on performance in the pooled sample of classes who received the feedback intervention either early or late by comparing students who received any feedback (“Feedback” = 1) with students who received no feedback (“Feedback” = 0). In order to investigate the role of timing of feedback, we then interact the treatment dummy “Feedback” with the variable indicating whether the respective class received the intervention early (“EarlyTiming” = 1) or late (“EarlyTiming” = 0). We thus begin by estimating the following OLS model:

$$\begin{aligned}
 PointsTest3 (GradeTest3)_i = & \\
 & \alpha + \beta Feedback_i + \gamma EarlyTiming_j + \delta Feedback * EarlyTiming_{ij} \\
 & + \zeta PointsTest1_i + \eta PointsTest2_i + \theta Covariates_i + \iota School_k + \varepsilon_{ijk} \quad (1)
 \end{aligned}$$

$PointsTest3_i$  are the percentage points in the final math exam of student  $i$ ,  $PointsTest1_i$  and  $PointsTest2_i$  are the percentage points in the second last and the last exam of student  $i$ ,  $Covariates_i$  is a vector of characteristics of student  $i$ : student  $i$ 's gender, whether student  $i$  has a non-German first and family name (to capture migration background),

whether student  $i$  has siblings, and whether student  $i$  has his or her own room at home.  $Feedback_i$  indicates whether student  $i$  received any type of feedback while  $EarlyTiming_j$  indicates that the class was treated 1-3 days before the exam.  $School_k$  controls for school fixed effects such that  $Feedback_i$  identifies the effect of feedback by comparing the results of students who received feedback with those who did not within the same school.<sup>27</sup>  $\varepsilon_{ijk}$  is a stochastic i.i.d. error term. While the number of points attained by students in the final exam captures their level of math knowledge, which is the socially relevant outcome, the students themselves might only care about their grade. For this reason, we estimate the model with students' percentage points in the final exam ( $PointsTest3_i$ ) as well as with the grades attained in this exam ( $GradeTest3_i$ ) as dependent variable.

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<sup>27</sup>Note that we have 19 experimental classes in 7 schools in total. However, in one school only one class participated and in another school both classes that participated were in the same class level treatment (this was possible because we blocked randomization on grade level). Thus in regressions that contain school fixed effects these three classes were dropped, which does not affect any of the main findings.

Table 2: Effects of Feedback on Performance: The Role of Timing

	Dep. Var.: Points Exam 3		Dep. Var.: Grade Exam 3	
	(1)	(2)	(3)	(4)
Feedback	0.004 (0.014)	-0.021* (0.013)	-0.006 (0.093)	0.189** (0.088)
Early Timing	0.063** (0.029)	0.027 (0.028)	-0.361* (0.184)	-0.081 (0.179)
Feedback * Early Timing		0.053** (0.023)		-0.409*** (0.139)
Points Exam 1	0.253*** (0.073)	0.250*** (0.074)	-2.194*** (0.397)	-2.166*** (0.397)
Points Exam 2	0.373*** (0.088)	0.374*** (0.088)	-2.225*** (0.483)	-2.236*** (0.478)
Female	-0.023 (0.019)	-0.023 (0.019)	0.100 (0.116)	0.100 (0.114)
SchoolFE	Yes	Yes	Yes	Yes
Pupil Controls	Yes	Yes	Yes	Yes
$N$	282	282	282	282
adj. $R^2$	0.390	0.393	0.421	0.426

*Note:* This table presents the overall effects of feedback as well as the interaction effects of feedback and timing on performance in the last exam using a linear regression model including school fixed effects. The dependent variable in columns 1 and 2 is percentage points in exam 3. The dependent variable in columns 3 and 4 is the grade in exam 3 (larger grades are worse grades). Covariates: percentage points in exam 1, percentage points in exam 2, gender, own room, foreign name, siblings. Standard errors are reported in parentheses, clustered at class level and corrected using bias-reduced linearization. The number of clusters is 16. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

The first and third column of Table 2 show that there was no significant overall effect of feedback on points and on grades. However, the second and fourth column show that the effect of feedback strongly depends on its timing. Students who received feedback immediately before the exam had on average 2.1 percentage points (0.12 standard deviations) less and about 0.2 worse grades (0.16 standard deviations)—on a scale from 1.0 (best grade) to 6.0 (worst grade)—than students who did not receive any feedback. These effects are significant at the 10% and the 5% level. Furthermore, when adding up

the coefficients of feedback and the interaction term of feedback and timing, we can see that when receiving feedback 1-3 days before the exam students tend to perform better than students who do not receive any feedback. They have on average 3.2 percentage points (0.18 standard deviations) more and 0.22 points (0.19 standard deviations) better grades than students receiving no feedback. However, the first effect is marginally not significant while the second effect is only significant at the 10% level.<sup>28</sup> These overall effects of timing are interesting because they give a first hint that timing matters for the effects of feedback. Moreover, as we also expect timing to interact with the type of feedback and whether the feedback conveys positive or negative information, we expect the overall effects of timing to disguise a large amount of heterogeneity. For this reason, we will investigate the role of reference frame of feedback in the next section.<sup>29</sup>

### The Role of Reference Frame of Feedback

In order to investigate the role of the reference frame of feedback, we estimate the following model:

$$PointsTest3_i (GradeTest3)_i = \alpha + \beta ChangeFeedback_i + \gamma LevelFeedback_i + \delta PointsTest1_i + \zeta PointsTest2_i + \eta Covariates_i + \theta Class_j + \varepsilon_{ij} \quad (2)$$

$PointsTest3_i$  are the percentage points and  $GradeTest3_i$  is the grade of student  $i$  in the final math exam.  $PointsTest1_i$  and  $PointsTest2_i$  are the percentage points in the second last and the last exam of student  $i$ ,  $Covariates_i$  is the same vector of characteristics of student  $i$  as in equation 1.  $Class_j$  controls for class fixed effects and  $\varepsilon_{ij}$  is a stochastic i.i.d. error term.

Since we found that timing of feedback is crucial for its effect, we analyze this model

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<sup>28</sup>p=0.112 and p=0.061, respectively, for the combined F-tests of the coefficients of “Feedback” and “Feedback \* Early Timing” in columns 2 and 4.

<sup>29</sup> Results when excluding school fixed effects, prior performance measures, and student characteristics can be found in Table E.1 in Appendix E.

separately for classes who had the intervention 1-3 days before and classes who had the intervention immediately before the exam. This allows us to investigate further why students seem to benefit from receiving feedback 1-3 days but not from receiving feedback immediately before the exam.

**Effects of change and level feedback when given early** Table 3 presents the results with respect to the reference frame of feedback for classes that were treated 1-3 days before the exam. As can be seen in the first and fourth column (“All”), both types of feedback lead to significantly higher exam scores and better grades than those of students in the same classes who did not receive any feedback. Students who received change and students who received level feedback have 3.8 (0.21 sd) and 3.9 percentage points (0.22 sd) higher outcomes (0.2 and 0.3 points, or 0.19 and 0.22 sd, better grades), respectively, than students in the control group. These effects are significant at the 10% and the 5% level (at the 10% and the 1% level).

Table 3: CHANGE FEEDBACK vs. LEVEL FEEDBACK vs. CONTROL - Class-Level Treatment: EARLY TIMING

	Dep. Var.: Points Exam 3			Dep. Var.: Grade Exam 3		
	(1)	(2)	(3)	(4)	(5)	(6)
	All	Pos Change	Neg Change	All	Pos Change	Neg Change
Change Feedback	0.038* (0.022)	0.002 (0.051)	0.081*** (0.027)	-0.220* (0.130)	0.048 (0.353)	-0.588*** (0.171)
Level Feedback	0.039** (0.016)	0.026 (0.037)	0.053** (0.025)	-0.254*** (0.092)	-0.181 (0.237)	-0.386** (0.164)
Points Exam 1	0.358*** (0.046)	0.318** (0.149)	0.473*** (0.127)	-2.581*** (0.440)	-2.367** (1.096)	-3.655*** (0.939)
Points Exam 2	0.297*** (0.067)	0.350*** (0.128)	0.161 (0.121)	-1.988*** (0.511)	-2.407** (0.967)	-0.543 (0.980)
Female	0.005 (0.029)	-0.006 (0.051)	0.020 (0.022)	-0.017 (0.184)	-0.005 (0.325)	-0.072 (0.125)
ClassFE	Yes	Yes	Yes	Yes	Yes	Yes
Pupil Controls	Yes	Yes	Yes	Yes	Yes	Yes
<i>N</i>	160	87	73	160	87	73
adj. <i>R</i> <sup>2</sup>	0.517	0.426	0.611	0.544	0.481	0.632

*Note:* This table presents the effect of change feedback and level feedback when given 1-3 days in advance using a linear regression model including class fixed effects. Column 1 and 4 present the results for the whole sample, columns 2 and 5 present the results for students whose rank improved from exam 1 to exam 2, and columns 3 and 6 present results for students whose rank worsened from exam 1 to exam 2. The dependent variable in columns 1, 2, and 3 is percentage points in exam 3. The dependent variable in columns 4, 5, and 6 is grades in exam 3 (larger grades are worse grades). Covariates: percentage points exam 1, percentage points exam 2, gender, own room, foreign name, siblings. Standard errors are reported in parentheses, clustered at class level and corrected using bias-reduced linearization. The number of clusters is 10. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Change feedback differed in its wording depending on whether one experienced a positive or a negative change in ranks. In case of a positive change it said that one's rank "improved", while in case of a negative change it said that one's rank "worsened". For this reason, we investigate in columns 2 and 3 for percentage points outcomes and in columns 5 and 6 for grade outcomes whether the response to change feedback that reported improvement differs from the response to change feedback that reported worsening. We, indeed, find that it does. Given that one had a positive change in ranks, it does not seem to matter whether students received feedback 1-3 days before the exam or not as

the estimated differences are very small and insignificant. However, if students had a negative change in ranks, receiving this feedback 1-3 days before the exam led students to have 8.1 percentage points (0.45 sd) and 0.6 grade points (0.50 sd) better outcomes than their classmates who did not receive any feedback. Both effects are highly significant at the 1% level.

Interestingly, it also seems to matter for feedback about rank level whether one previously experienced an improvement or worsening in performance as the significant effect of level feedback seems to be driven more strongly by students who recently suffered a decrease in their performance. It might be that level feedback also tended to be more disappointing, and thus more motivating, in case one's performance had dropped.<sup>30</sup> While students in the change feedback treatments most likely interpret a positive and a negative change feedback as a positive and a negative signal, it is unclear ex ante whether students in the level feedback treatment interpret their rank feedback as a positive or negative signal. As we elicited students' confidence in their mathematics ability after the intervention, we can investigate the effects of different types of feedback on ability beliefs and will do so further below.

Our results thus provide evidence that, indeed, early level feedback significantly improves exam performance.<sup>31</sup>

**Effects of change and level feedback when given late** Table 4 presents the results with respect to the reference frame of feedback for classes that were treated immediately before the exam. Overall, neither change feedback nor level feedback had a significant effect on students' points when they are compared to students within their own class. When looking at students' grades we find a negative effect of 0.3 grade points (0.26 sd) of receiving negative change feedback. This effect is significant at the 5% level. There seems to be heterogeneity in effects. The coefficient of change feedback has a positive sign for students who improved (column 2) and a negative sign for students who worsened

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<sup>30</sup>F-tests show that the coefficients of the change feedback and the level feedback in column 3 and column 6, respectively, are not significantly different from each other.

<sup>31</sup>Results when excluding class fixed effects, prior performance measures, and student characteristics can be found in Tables E.2 and E.3 in Appendix E.

(column 3). However, these results are not definite.

Table 4: CHANGE FEEDBACK vs. LEVEL FEEDBACK vs. CONTROL - Class-Level Treatment: LATE TIMING

	Dep. Var.: Points Exam 3			Dep. Var.: Grade Exam 3		
	(1)	(2)	(3)	(4)	(5)	(6)
	All	Pos Change	Neg Change	All	Pos Change	Neg Change
Change Feedback	-0.002 (0.018)	0.022 (0.040)	-0.029 (0.023)	0.105 (0.106)	-0.037 (0.240)	0.312** (0.149)
Level Feedback	-0.022 (0.020)	-0.009 (0.031)	-0.023 (0.046)	0.176 (0.121)	0.025 (0.181)	0.271 (0.289)
Points Exam 1	0.125 (0.122)	0.105 (0.293)	0.382*** (0.129)	-1.522*** (0.580)	-2.171 (1.399)	-2.832*** (0.813)
Points Exam 2	0.437*** (0.110)	0.429 (0.269)	0.256* (0.137)	-2.818*** (0.499)	-2.161 (1.353)	-1.743** (0.797)
Female	-0.041 (0.031)	-0.047 (0.039)	-0.021 (0.028)	0.159 (0.160)	0.135 (0.162)	0.093 (0.205)
ClassFE	Yes	Yes	Yes	Yes	Yes	Yes
Pupil Controls	Yes	Yes	Yes	Yes	Yes	Yes
$N$	159	76	83	159	76	83
adj. $R^2$	0.361	0.204	0.456	0.393	0.289	0.436

*Note:* This table presents the effect of change feedback and level feedback when given immediately before the exam using a linear regression model including class fixed effects. Columns 1 and 4 present the results for the whole sample, columns 2 and 5 present the results for students whose rank improved from exam 1 to exam 2, and columns 3 and 6 present results for students whose rank worsened from exam 1 to exam 2. The dependent variable in columns 1, 2, and 3 is percentage points in exam 3. The dependent variable in columns 4, 5, and 6 is grades in exam 3 (larger grades are worse grades). Covariates: percentage points exam 1, percentage points exam 2, gender, own room, foreign name, siblings. Standard errors are reported in parentheses, clustered at class level and corrected using biased-reduced linearization. The number of clusters is 9. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

**Possible spillover effects when feedback is given early** Note that the above analyses identify the effects of feedback on performance by comparing students within EARLY TIMING and LATE TIMING classes with students who did not receive any feedback. No spillover effects of feedback on students in the control group are possible in LATE TIMING classes as students could not find out anything about the feedback other students received (all students were already seated separately to write the exam and received sheets formatted in the same way). However, the positive effect of feedback in EARLY TIMING

classes could possibly be affected by spillover effects of our intervention on students who did not receive any feedback. For example, students who found out after our intervention but before the exam that their classmates received feedback while they did not could have been discouraged, leading them to perform worse in the exam compared to a situation where their classmates were not treated. This would cause the positive effect of feedback to be overestimated. Alternatively, the spillover effects could go in the other direction and students who did not receive any feedback in the EARLY TIMING class could, by interacting with those who did receive feedback, become more motivated and perform better in the exam. This would cause us to underestimate the benefits of feedback in EARLY TIMING. To address the question of whether there were spillover effects in EARLY TIMING classes, we compare the results of students in the control groups of EARLY TIMING and LATE TIMING classes. This is a valid procedure because all treatments are balanced in terms of prior performance so potential differences post-intervention performance are due to the intervention.

As can be seen in Table 2 in columns 2 and 4, the control group in classes where spillover effects were possible (EARLY TIMING) tend to have better outcomes (of 2.7 percentage points, or 0.08 grade points) than their counterparts in classes where no spillover effects were possible (LATE TIMING). However, this difference is insignificant. We infer that, if anything, spillover effects of our intervention on the control group were positive and that possible positive effects of early feedback (level and change feedback) would be lower bound estimates, i.e. we tend to underestimate these treatment effects.

**Power calculations** We follow Azmat et al. (2018) and assess the power of our analysis in the EARLY TIMING condition and LATE TIMING condition reported in Tables 3 and 4 by considering several plausible scenarios with respect to the potential magnitude of the underlying effect. These are (i) the conservative scenario in which the treatment might have no effect or an effect on the outcome variable of 5% of a standard deviation, (ii) the intermediate scenario with an effect size of 15% of a standard deviation, or (iii) the least conservative scenario with an effect size of 25% of a standard deviation. For each class-level treatment (EARLY TIMING and LATE TIMING) we separately calculate

the power for each one of the scenarios taking the structure of our data into account. In multiple sites, students within a class were randomized into treatments (CONTROL, CHANGE FEEDBACK, LEVEL FEEDBACK). We account therefore for the proportion of explained variance by the blocking variable (the classroom) and the explained variance by the covariates.<sup>32</sup> If the true effect size was 5% of a standard deviation, our field experiment would be able to detect the effect of the treatment on exam performance with a probability of around 12% in both class-level treatments, hence would be considered under-powered to detect the most conservative scenario. If the true effect size was 15% of a standard deviation, which is an effect size found by Azmat and Iriberry (2010) and Blanes i Vidal and Nossol (2011), we would be able to detect this effect with a probability of around 33% (early) and 27% (late). Our study is able to detect an effect of 25% of a standard deviation with a probability of around 65% (early) and 53% (late). The magnitude of our main findings is in this range and they can thus be identified with sufficient power. It is likely, however, that some of the smaller effects that turn out insignificant in our study would become significant with a larger sample size.

**Gender differences** While gender differences are not the main focus of our paper, we expect the effectiveness of feedback to depend on ex-ante confidence in the level of past performance. Furthermore, it has widely been shown that male subjects are more confident about their abilities than female subjects (Barber and Odean, 2001; Niederle and Vesterlund, 2007). For this reason, we shortly report the results of a heterogeneity analysis by gender with respect to performance. In the next section, we will then investigate the effects of feedback on confidence, which will also allow us to draw inferences with respect to ex-ante gender differences in confidence.

Interestingly, as shown in Table F.1 in Appendix F, the overall positive effect of both change and level feedback in the early treatment is driven by the response of boys. They have 5.9 and 7.4 percentage points (0.33 sd and 0.41 sd) better results in the change and level treatment, respectively, than boys in the control group. At the same time, there is no significant difference for girls in any of the two treatment groups and the control group.

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<sup>32</sup>We use the *optimal design* software package for power calculations.

The coefficients of the treatment dummies and the interaction term of the treatment and the female indicator add up to an almost perfect zero effect for both types of feedback. However, we find that both boys and girls respond positively to feedback about negative changes, as the coefficient of the interaction term of change feedback and female is very small and insignificant. Analyses for classes that received feedback late reveal that neither the results of boys nor the results of girls are influenced by any feedback given late.<sup>33</sup>

## 5.4 Psychological Mechanisms

In this section we explore several psychological mechanisms that might contribute to explaining the effects of feedback on performance, which has—to our knowledge—not been done in previous studies. First, we look at whether the effects of feedback on outcomes can be explained by changes in students' confidence in their mathematics ability and their belief in the effectiveness of their learning effort. Then, we will investigate whether feedback influenced students' emotions by analyzing whether it affected their state self-esteem.<sup>34</sup>

**Effects of feedback on students' confidence in their mathematics ability** As described above, we expect the effectiveness of feedback to depend on whether the feedback is perceived as positively or negatively surprising. We chose not to elicit students' expectations before the intervention in order to avoid the risk of creating an unnatural framing for the information we were to provide. However, we can indirectly infer whether students were positively or negatively surprised by their feedback by analyzing the effect

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<sup>33</sup>Furthermore, heterogeneous effects could also be expected for marginal and non-marginal students. In our setting, a student at the margin would be a student whose current grade (the average of the grades in the first exam and second exam) could be changed by the grade obtained in the final exam of the semester. However, this applies to every student in our sample which is why we cannot differentiate between marginal and non-marginal students. Independently of the average grade obtained in the first and second exam, there is always a grade in the final exam which could change the overall course grade. However, one could argue that only those students who obtained a different grade in the two previous exams perceive themselves as being at the margin. We could then compare the effect of feedback on those students compared to students who obtained the same grades in the two previous exams. However, only about 15% of students in our sample have the same grade in the first and in the second exam.

<sup>34</sup>Note that, unlike in the regressions with test scores as dependent variable, we do not have pre-intervention information on students' effort-effectiveness belief or self-esteem to control for level differences. Effort-effectiveness beliefs and self-esteem were elicited in EARLY TIMING classes as there the feedback intervention was immediately followed by an extended questionnaire.

of feedback on students' confidence elicited after the intervention. If the feedback is positively surprising, students' confidence in their mathematics ability should be positively affected by it relative to the control group, while if the feedback is negatively surprising, students' confidence should be negatively affected by it relative to the control group. As can be seen in Table G.1, level feedback did not have any overall effect on confidence. Interestingly, however, if we split the sample by gender we find that level feedback significantly decreases boys' confidence by almost 0.3 standard deviations. The effect on girls' confidence is positive and of the same magnitude (but insignificant), which explains why the overall effect of level feedback on confidence is close to zero. It seems to be the case that boys overestimated their mathematics ability in the absence of feedback and, realizing they were not as good as they thought, they increased learning effort in response to the feedback which then resulted in better performance for them. Girls, on the other hand, if anything positively update their beliefs about their mathematics ability and therefore the feedback did not motivate them to study more. We can also see in Table G.1 that girls generally tend to have lower confidence in their mathematics ability than boys by about 0.3 standard deviations but that this difference is not significant.

**Effects of feedback on students' effort-effectiveness belief** The "growth mindset" hypothesis described in Section 3 predicts that making changes in past performance salient reinforces the belief that one's outcomes can be influenced by one's effort. We therefore expected level feedback not to influence this belief. Table G.2 in Appendix G shows that students who received change feedback report a weakly significant 0.17 standard deviations higher effort-effectiveness belief than students in the control group. Furthermore, the results show that level feedback tends not to influence this belief overall. When we analyze the effect of feedback on the effort-effectiveness belief separately by gender, we see that, unlike expected and similar to the effect on confidence in mathematics ability, level feedback has a significantly negative effect on boys while it has a significantly positive effect on girls. It seems that students do not cognitively differentiate between these two ability beliefs to the degree we expected. Rather, positively surprising information, even if it refers to a different ability dimension, raises the effort-effectiveness belief, while

negatively surprising information lowers it.

**Effects of feedback on students' self-esteem** We expected that negative change feedback would on average be emotionally disappointing to students while positive change feedback would on average cheer them up. Furthermore, if students are on average overconfident, as has been suggested by the literature, level feedback will be disappointing. Table G.3 in Appendix G shows that feedback tends to have a negative effect on students' self-esteem but the overall estimates are either insignificant or only marginally significant.

As we found that boys largely drive our effects of feedback on performance, and that boys' confidence responds significantly negatively to feedback while girls' confidence tends to respond positively, we expect to see similar patterns with respect to state self-esteem. In fact, as shown in Table G.3 in Appendix G boys' self-esteem is significantly reduced by about half a standard deviation by both change and level feedback, while girls' self-esteem is increased by change feedback by almost half a standard deviation and does not significantly respond to level feedback. This suggests that the emotional effects of feedback on performance strongly depend on whether the feedback is seen as disappointing or not.

## 6 Conclusion

We investigated factors that may explain why feedback sometimes has positive and sometimes negative effects on performance. To do so we implemented a randomized feedback intervention in secondary schools. We varied the timing and the reference frame of relative performance feedback to analyze their causal effects on performance in a high-stakes mathematics exam. With respect to timing, we compare students who received feedback either 1-3 days before the last math exam of the semester to students receiving the feedback immediately before the exam started. Concerning the reference frame of feedback, students within the same class received either feedback about their absolute rank in the preceding exam, feedback about their change in ranks between the two preceding exams, or no feedback.

We find that level feedback and change feedback significantly improve outcomes in the final exam when given early but tend to decrease outcomes when given shortly before the exam. Moreover, these effects are driven by students who experienced a recent decline in (relative) performance and feedback has particularly strong effects on boys. We do not find significant effects of level and change feedback for students who experienced an increase in (relative) performance.

To shed light on potential (psychological) mechanisms that may contribute towards the explanation of our results, we investigate the effect of feedback on students' confidence in their mathematics ability, their belief in the effectiveness of learning effort, and their state self-esteem. Our results reveal heterogeneous gender effects. While level feedback significantly decreases the state self-esteem, math confidence and effort-effectiveness belief of boys, level feedback significantly increases the effort-effectiveness belief of girls. Moreover, change feedback significantly decreases the state self-esteem of boys while increasing it for girls. An interpretation of these findings could be that feedback lowers boys' level of overconfidence which in turn increases their perceived necessity to study for the exam. Our results provide first insights into potential psychological mechanisms underlying the effects of feedback on performance in school setting and we hope that future research based on laboratory experiments and other field-experimental settings will help to substantiate our findings.

Our results suggest that making negative information about past performance salient may significantly improve performance in a high-stakes environment when it is given early enough. However, when it is given too late, a negative emotional effect may dominate a positive incentive effect of information provision. Our results give interesting insights into the psychological and behavioral effects of relative performance feedback in an educational setting—and in other situations where the ability to motivate people is crucial—and have two important implications for the design of feedback: (i) feedback works better if given a few days in advance of a high-stakes task, and (ii) supervisors should not shy away from giving negative feedback.

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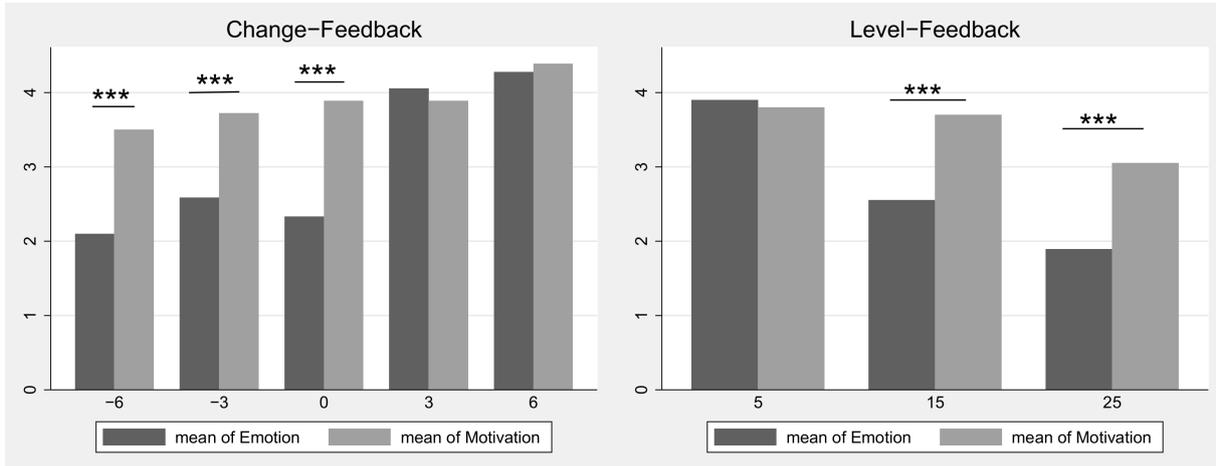
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# Appendix

## A Results of Pre-experimental Survey

Figure A.1: Pretest - Predicted Emotions and Motivation by Reference Frame of Feedback



*Note:* This graph shows the results of a pretest separately for change feedback (left) and level feedback (right). Dark bars are mean responses to the question *How do you think does Paul feel after reading the note?*, gray bars are mean responses to the question *How much do you think is Paul motivated to exert effort in the upcoming math exam?*. Both are measured on a 1 to 5 scale. Feedback notes in the pretest were varied such that students faced either a change in Paul’s rank of -6, -3, 0, 3 or 6 or the ranks 5, 15 or 25. Differences between emotions and motivation were tested with a mean-comparison tests. The pretest was conducted with 151 students of the same age group (grades 5 and 6) but these students did not participate in the main experiment.

## B Feedback Notes

Figure B.1: Feedback Note - CONTROL Group [translated from German]

Dear [Student Name],

I wish you great success in your exam!

[Teacher Name]

Figure B.2: Feedback Note - CHANGE FEEDBACK Treatment [translated from German]

Dear [Student Name],

I compared the points of each student in the class in the last two exams.

**Relative to your classmates, you improved/worsened your performance in the last math exam by XX places.**

I wish you great success in your exam!

[Teacher Name]

Figure B.3: Feedback Note - LEVEL FEEDBACK Treatment  
[translated from German]

Dear [Student Name],

I looked at the points of each student in the class in the last exam.

**Relative to your classmates you achieved, with your performance in the last math exam, the XXth place.**

I wish you great success in your exam!

[Teacher Name]

## C Balance and Randomization Checks

Table C.1: Randomization Check Class-Level Treatments

	(1) Late-Feedback Treatment	(2) Early- Feedback Treatment	(3) Overall	(4) (1) vs. (2), p-value
Female Teacher	0.793 (0.031)	0.781 (0.031)	0.787 (0.022)	0.781
Class Size	27.782 (0.244)	27.242 (0.250)	27.509 (0.175)	0.123
Age	23.667 (0.816)	24.708 (0.802)	24.193 (0.572)	0.363
Points Exam1	0.712 (0.014)	0.681 (0.014)	0.696 (0.010)	0.105
Points Exam2	0.719 (0.014)	0.730 (0.013)	0.725 (0.009)	0.554
Rank Exam1	0.495 (0.022)	0.490 (0.021)	0.493 (0.015)	0.889
Rank Exam2	0.467 (0.021)	0.493 (0.022)	0.481 (0.015)	0.399
Change in Rank	0.523 (0.592)	-0.028 (0.577)	0.243 (0.413)	0.505
Share Worsen	0.506 (0.038)	0.455 (0.037)	0.480 (0.027)	0.343
Share Participants	0.775 (0.015)	0.703 (0.012)	0.739 (0.010)	0.000
Female Pupil	0.480 (0.038)	0.449 (0.037)	0.464 (0.027)	0.570
Single Room	0.655 (0.046)	0.596 (0.048)	0.625 (0.033)	0.370
Internet	1.115 (0.072)	1.022 (0.073)	1.068 (0.051)	0.366
A-Level	2.034 (0.103)	2.056 (0.099)	2.045 (0.071)	0.879
Car	1.333 (0.078)	1.303 (0.078)	1.318 (0.055)	0.785
Siblings	1.299 (0.094)	1.489 (0.099)	1.395 (0.068)	0.165
Books at Home	1.983 (0.110)	2.140 (0.111)	2.063 (0.078)	0.314
<i>N</i>	174	178	352	
Proportion	0.494	0.506	1.000	

*Note:* This table reports group means of key characteristics for the LATE TIMING (column (1)) and EARLY TIMING (column (2)) treatments. Column (3) presents means for the pooled sample. Variable Age is reported in month starting with children born in June 2002 (Age=1). Standard errors are displayed in parentheses. Column and 4 reports the p-values of the two-sided t-test of equality of means between column (1) and column (2).

Table C.2: Randomization Check Student-Level Treatments - EARLY TIMING

	(1) Control	(2) Change	(3) Level	(4) (1) vs. (2), p-value	(5) (1) vs. (3), p-value	(6) (2) vs. (3), p-value
Female Teacher	0.782 (0.056)	0.780 (0.054)	0.781 (0.052)	0.978	0.994	0.983
Class Size	27.255 (0.452)	27.322 (0.429)	27.156 (0.424)	0.914	0.874	0.784
Age	23.750 (1.069)	23.415 (1.005)	23.286 (1.080)	0.820	0.761	0.930
Points Exam1	0.691 (0.025)	0.661 (0.027)	0.690 (0.021)	0.422	0.967	0.407
Points Exam2	0.733 (0.023)	0.732 (0.022)	0.727 (0.021)	0.976	0.845	0.866
Rank Exam1	0.472 (0.038)	0.510 (0.038)	0.488 (0.035)	0.487	0.751	0.678
Rank Exam2	0.482 (0.041)	0.487 (0.038)	0.508 (0.037)	0.934	0.637	0.687
Change in Rank	-0.382 (0.959)	0.763 (1.048)	-0.453 (0.988)	0.424	0.959	0.400
Share Worsen	0.455 (0.068)	0.458 (0.065)	0.453 (0.063)	0.974	0.988	0.960
Share Participants	0.710 (0.022)	0.701 (0.021)	0.699 (0.020)	0.751	0.706	0.959
Female Pupil	0.418 (0.067)	0.424 (0.065)	0.500 (0.063)	0.953	0.376	0.401
Single Room	0.765 (0.060)	0.759 (0.059)	0.707 (0.060)	0.948	0.500	0.536
Internet	1.100 (0.096)	1.315 (0.102)	1.241 (0.111)	0.129	0.345	0.628
A-level	2.347 (0.132)	2.453 (0.088)	2.582 (0.085)	0.500	0.130	0.292
Car	1.471 (0.106)	1.648 (0.113)	1.518 (0.088)	0.255	0.731	0.363
Siblings	1.462 (0.093)	1.288 (0.084)	1.466 (0.086)	0.170	0.975	0.145
Books at Home	2.231 (0.144)	2.679 (0.182)	2.379 (0.151)	0.057	0.481	0.205
<i>N</i>	55	59	64			
Proportion	0.309	0.331	0.360			

*Note:* This table reports group means of key characteristics for the student-level treatments (control, change, level) of EARLY TIMING classes in columns (1)-(3). Variable Age is reported in month starting with children born in June 2002 (Age=1). Standard errors are displayed in parentheses. Columns (4)-(6) report the p-values of the two-sided t-test of equality of means between the treatments.

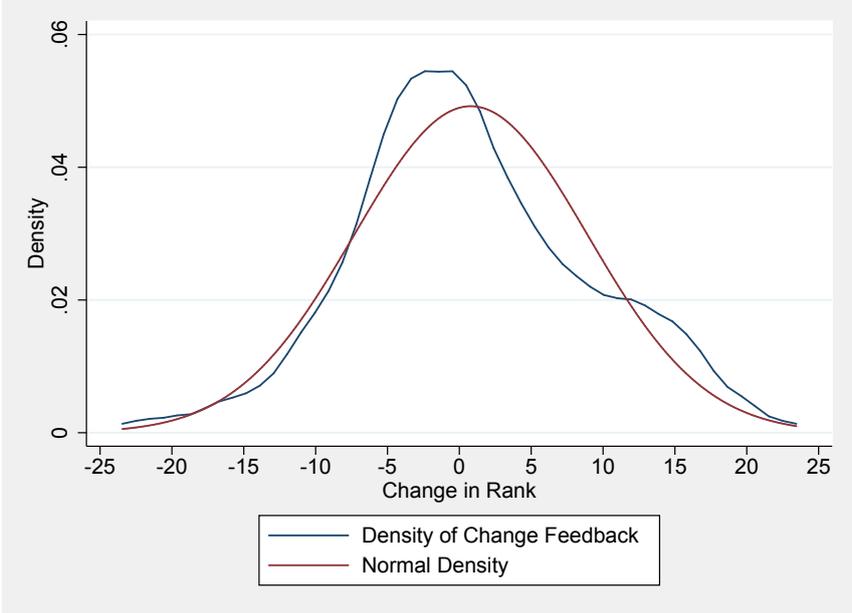
Table C.3: Randomization Check Student-Level Treatments - LATE TIMING

	(1) Control	(2) Change	(3) Level	(4) (1) vs. (2), p-value	(5) (1) vs. (3), p-value	(6) (2) vs. (3), p-value
Female Teacher	0.782 (0.056)	0.789 (0.054)	0.800 (0.052)	0.922	0.813	0.889
Class Size	27.782 (0.429)	27.877 (0.421)	27.667 (0.437)	0.874	0.852	0.730
Age	22.667 (1.174)	22.075 (1.086)	22.429 (1.136)	0.712	0.885	0.823
Points Exam1	0.745 (0.022)	0.708 (0.024)	0.703 (0.022)	0.264	0.179	0.871
Points Exam2	0.730 (0.024)	0.712 (0.024)	0.717 (0.023)	0.581	0.681	0.881
Rank Exam1	0.438 (0.039)	0.502 (0.040)	0.522 (0.034)	0.253	0.105	0.706
Rank Exam2	0.457 (0.038)	0.470 (0.036)	0.475 (0.036)	0.800	0.728	0.924
Change in Rank	-0.600 (1.044)	0.842 (1.091)	1.250 (0.943)	0.342	0.190	0.777
Share Worsen	0.527 (0.068)	0.544 (0.067)	0.467 (0.065)	0.862	0.520	0.408
Share Participants	0.778 (0.026)	0.772 (0.026)	0.770 (0.025)	0.861	0.812	0.953
Female Pupil	0.418 (0.067)	0.544 (0.067)	0.475 (0.066)	0.186	0.549	0.460
Single Room	0.745 (0.062)	0.811 (0.054)	0.804 (0.054)	0.421	0.474	0.919
Internet	1.235 (0.107)	1.255 (0.108)	1.411 (0.095)	0.898	0.220	0.278
A-level	2.511 (0.113)	2.320 (0.119)	2.604 (0.091)	0.251	0.518	0.059
Car	1.431 (0.106)	1.491 (0.106)	1.655 (0.120)	0.694	0.168	0.309
Siblings	1.220 (0.108)	1.245 (0.104)	1.268 (0.097)	0.866	0.742	0.874
Books at Home	2.160 (0.167)	2.189 (0.155)	2.382 (0.173)	0.900	0.361	0.409
<i>N</i>	55	57	60			
Proportion	0.320	0.331	0.349			

*Note:* This table reports group means of key characteristics for the student-level treatments (control, change, level) of LATE TIMING classes in columns (1)-(3). Variable Age is reported in month starting with children born in June 2002 (Age=1). Standard errors are displayed in parentheses. Columns (4)-(6) report the p-values of the two-sided t-test of equality of means between the treatments.

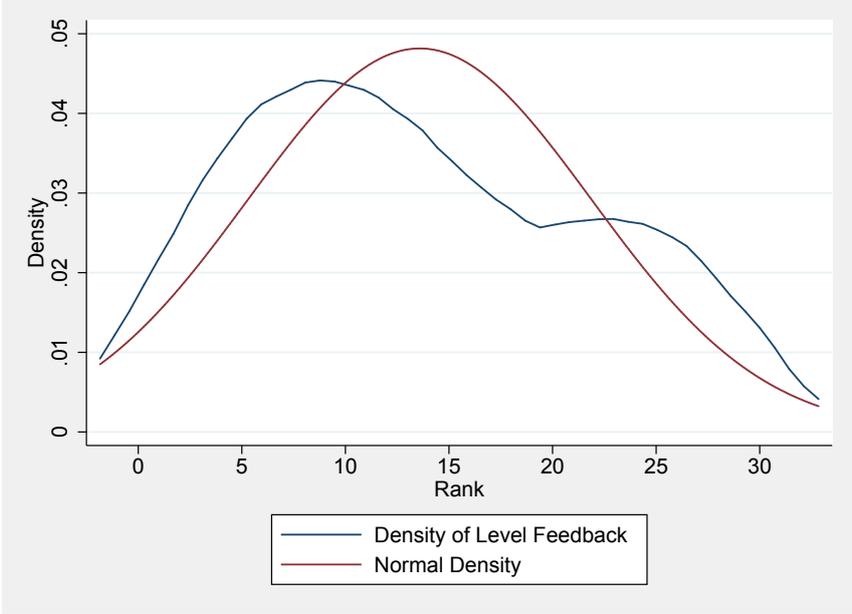
# D Graphs

Figure D.1: Feedback in CHANGE FEEDBACK Treatment



*Note:* This graph shows kernel density estimates for the feedback students received in the CHANGE FEEDBACK Treatment.

Figure D.2: Feedback in LEVEL FEEDBACK Treatment



*Note:* This graph shows kernel density estimates for the feedback students received in the LEVEL FEEDBACK Treatment.

## E Robustness Checks

Table E.1: Robustness Checks - Class-Level Treatments

	Dep. Var.: Points Exam 3			Dep. Var.: Grade Exam 3		
	(1)	(2)	(3)	(4)	(5)	(6)
Feedback	-0.040** (0.019)	-0.039** (0.017)	-0.022 (0.013)	0.326** (0.150)	0.309** (0.136)	0.199** (0.093)
Early Timing	0.030 (0.035)	0.021 (0.040)	0.032 (0.026)	-0.088 (0.207)	-0.025 (0.233)	-0.129 (0.168)
Feedback * Early Timing	0.063** (0.026)	0.062** (0.025)	0.051** (0.023)	-0.500*** (0.193)	-0.476** (0.187)	-0.407*** (0.141)
Points Exam 1			0.242*** (0.073)			-2.131*** (0.371)
Points Exam 2			0.374*** (0.088)			-2.229*** (0.457)
Female			-0.026 (0.018)			0.139 (0.114)
SchoolFE	No	Yes	No	No	Yes	No
Pupil Controls	No	No	Yes	No	No	Yes
<i>N</i>	282	282	282	282	282	282
adj. <i>R</i> <sup>2</sup>	0.041	0.089	0.381	0.034	0.099	0.409

*Note:* This table presents the effect of feedback timing on performance in the last exam using a linear regression model. The dependent variable in columns 1, 2 and 3 is percentage points in exam 3. The dependent variable in columns 4, 5 and 6 is the grade in exam 3. Columns 1 and 4 do not contain any control variables. Columns 2 and 5 contain school fixed effects but no other control variables. Columns 3 and 6 control for percentage points exam 1, percentage points exam 2, gender, own room, foreign name, and siblings but do not contain school fixed effects. Standard errors are reported in parentheses, clustered at class level and corrected using bias-reduced linearization. The number of clusters is 16. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table E.2: Robustness Checks - Student-Level Treatments in EARLY TIMING - Points

	Dep. Var.: Points in Exam 3								
	All	All	All	Pos Change	Pos Change	Pos Change	Neg Change	Neg Change	Neg Change
Change Feedback	0.027 (0.019)	0.024 (0.020)	0.033 (0.020)	-0.031 (0.053)	-0.033 (0.055)	-0.014 (0.048)	0.095*** (0.024)	0.094*** (0.018)	0.089** (0.035)
Level Feedback	0.025 (0.019)	0.029 (0.020)	0.030* (0.017)	-0.009 (0.036)	0.001 (0.041)	0.016 (0.039)	0.066*** (0.018)	0.073** (0.029)	0.053 (0.034)
Points Exam 1			0.314*** (0.044)			0.191 (0.132)			0.511*** (0.150)
Points Exam 2			0.280*** (0.106)			0.480*** (0.084)			0.081 (0.187)
Female			-0.006 (0.030)			-0.005 (0.046)			-0.009 (0.038)
ClassFE	No	Yes	No	No	Yes	No	No	Yes	No
Pupil Controls	No	No	Yes	No	No	Yes	No	No	Yes
<i>N</i>	160	160	160	87	87	87	73	73	73
adj. <i>R</i> <sup>2</sup>	-0.008	0.155	0.407	-0.019	0.082	0.363	0.028	0.264	0.482

*Note:* This table presents the effect of change feedback and level feedback when given 1-3 days in advance using a linear regression model. Dependent variable: percentage points in exam 3. Columns 1, 4, and 7 do not contain any control variables. Columns 2, 5, and 8 contain class fixed effects but no other control variables. Columns 3, 6, and 9 control for percentage points exam 1, percentage points exam 2, gender, own room, foreign name, and siblings but do not contain class fixed effects. Standard errors are reported in parentheses, clustered at class level and corrected using bias-reduced linearization. The number of clusters is 10. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table E.3: Robustness Checks - Student-Level Treatments in EARLY TIMING - Grade

	Dep. Var.: Grade in Exam 3								
	All	All	All	Pos Change	Pos Change	Pos Change	Neg Change	Neg Change	Neg Change
Change Feedback	-0.124 (0.136)	-0.113 (0.131)	-0.177 (0.120)	0.310 (0.378)	0.310 (0.377)	0.173 (0.337)	-0.634*** (0.213)	-0.663*** (0.124)	-0.599** (0.268)
Level Feedback	-0.142 (0.126)	-0.172 (0.134)	-0.196* (0.101)	0.074 (0.250)	-0.000 (0.280)	-0.100 (0.253)	-0.405*** (0.152)	-0.499*** (0.172)	-0.343 (0.271)
Points Exam 1			-2.214*** (0.439)			-1.524 (0.991)			-3.652*** (1.096)
Points Exam 2			-1.859** (0.832)			-3.069*** (0.796)			-0.342 (1.512)
Female			0.063 (0.201)			0.023 (0.289)			0.099 (0.262)
ClassFE	No	Yes	No	No	Yes	No	No	Yes	No
Pupil Controls	No	No	Yes	No	No	Yes	No	No	Yes
<i>N</i>	160	160	160	87	87	87	73	73	73
adj. <i>R</i> <sup>2</sup>	-0.009	0.153	0.399	-0.012	0.091	0.382	0.025	0.284	0.440

*Note:* This table presents the effect of change feedback and level feedback when given 1-3 days in advance using a linear regression model. Dependent variable: grade in exam 3. Columns 1, 4, and 7 do not contain any control variables. Columns 2, 5, and 8 contain class fixed effects but no other control variables. Columns 3, 6, and 9 control for percentage points exam 1, percentage points exam 2, gender, own room, foreign name, and siblings but do not contain class fixed effects. Standard errors are reported in parentheses, clustered at class level and corrected using bias-reduced linearization. The number of clusters is 10. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table E.4: Robustness Checks - Student-Level Treatments in LATE TIMING - Points

	Dep. Var.: Points in Exam 3								
	All	All	All	Pos Change	Pos Change	Pos Change	Neg Change	Neg Change	Neg Change
Change Feedback	-0.018 (0.023)	-0.018 (0.021)	-0.001 (0.017)	-0.028 (0.030)	-0.012 (0.031)	0.015 (0.037)	-0.006 (0.044)	-0.025 (0.030)	-0.011 (0.025)
Level Feedback	-0.044** (0.022)	-0.040** (0.019)	-0.025 (0.019)	-0.035 (0.028)	-0.016 (0.028)	-0.024 (0.034)	-0.059 (0.043)	-0.064* (0.036)	-0.015 (0.038)
Points Exam 1			0.180 (0.114)			0.139 (0.258)			0.391*** (0.126)
Points Exam 2			0.462*** (0.107)			0.435* (0.248)			0.346*** (0.116)
Female			-0.044 (0.029)			-0.055 (0.043)			-0.027 (0.029)
ClassFE	No	Yes	No	No	Yes	No	No	Yes	No
Pupil Controls	No	No	Yes	No	No	Yes	No	No	Yes
<i>N</i>	159	159	159	76	76	76	83	83	83
adj. <i>R</i> <sup>2</sup>	-0.001	0.138	0.314	-0.019	0.043	0.183	-0.000	0.242	0.354

*Note:* This table presents the effect of change feedback and level feedback when given 1-3 days in advance using a linear regression model. Dependent variable: percentage points in exam 3. Columns 1, 4, and 7 do not contain any control variables. Columns 2, 5, and 8 contain class fixed effects but no other control variables. Columns 3, 6, and 9 control for percentage points exam 1, percentage points exam 2, gender, own room, foreign name, and siblings but do not contain class fixed effects. Standard errors are reported in parentheses, clustered at class-level and corrected using bias-reduced linearization. The number of clusters is 9. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table E.5: Robustness Checks - Student-Level Treatments in LATE TIMING - Grade

	Dep. Var.: Grade in Exam 3								
	All	All	All	Pos Change	Pos Change	Pos Change	Neg Change	Neg Change	Neg Change
Change Feedback	0.213 (0.177)	0.204 (0.156)	0.124 (0.105)	0.247 (0.222)	0.182 (0.237)	-0.022 (0.209)	0.166 (0.339)	0.234 (0.240)	0.266 (0.177)
Level Feedback	0.347** (0.162)	0.299** (0.144)	0.223** (0.104)	0.116 (0.170)	0.019 (0.159)	0.092 (0.177)	0.614* (0.335)	0.545* (0.284)	0.324 (0.251)
Points Exam 1			-1.860*** (0.543)			-2.196* (1.225)			-2.888*** (0.853)
Points Exam 2			-2.652*** (0.462)			-1.923 (1.164)			-1.956*** (0.630)
Female			0.158 (0.156)			0.165 (0.171)			0.098 (0.214)
ClassFE	No	Yes	No	No	Yes	No	No	Yes	No
Pupil Controls	No	No	Yes	No	No	Yes	No	No	Yes
<i>N</i>	159	159	159	76	76	76	83	83	83
adj. <i>R</i> <sup>2</sup>	0.002	0.113	0.355	-0.019	-0.012	0.282	0.023	0.200	0.375

*Note:* This table presents the effect of change feedback and level feedback when given 1-3 days in advance using a linear regression model. Dependent variable: grade in exam 3. Columns 1, 4, and 7 do not contain any control variables. Columns 2, 5, and 8 contain class fixed effects but no other control variables. Columns 3, 6, and 9 control for percentage points exam 1, percentage points exam 2, gender, own room, foreign name, and siblings but do not contain class fixed effects. Standard errors are reported in parentheses, clustered at class level and corrected using bias-reduced linearization. The number of clusters is 9. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

## F Gender Differences

Table F.1: CHANGE FEEDBACK vs. LEVEL FEEDBACK vs. CONTROL - Class-Level Treatment: EARLY TIMING (Interaction with gender)

	Dep. Var.: Points in Exam 3			Dep. Var.: Grade in Exam 3		
	All	Pos Change	Neg Change	All	Pos Change	Neg Change
Change Feedback	0.059** (0.024)	0.050 (0.054)	0.084** (0.041)	-0.372** (0.149)	-0.185 (0.380)	-0.688** (0.318)
Change Feedback X Female	-0.051* (0.028)	-0.119* (0.064)	-0.006 (0.058)	0.351* (0.199)	0.592* (0.350)	0.246 (0.420)
Level Feedback	0.074*** (0.011)	0.096*** (0.031)	0.066 (0.049)	-0.451*** (0.079)	-0.609*** (0.216)	-0.437 (0.314)
Level Feedback X Female	-0.073** (0.031)	-0.161*** (0.053)	-0.023 (0.074)	0.417** (0.202)	0.973*** (0.286)	0.122 (0.481)
Points Exam 1	0.363*** (0.044)	0.326** (0.123)	0.483*** (0.161)	-2.605*** (0.425)	-2.430** (0.939)	-3.701*** (1.158)
Points Exam 2	0.293*** (0.074)	0.337*** (0.117)	0.148 (0.147)	-1.988*** (0.541)	-2.297*** (0.842)	-0.515 (1.129)
Female	0.049 (0.038)	0.094* (0.054)	0.030 (0.055)	-0.289 (0.224)	-0.569* (0.311)	-0.199 (0.363)
ClassFE	Yes	Yes	Yes	Yes	Yes	Yes
Pupil Controls	Yes	Yes	Yes	Yes	Yes	Yes
<i>N</i>	160	87	73	160	87	73
adj. <i>R</i> <sup>2</sup>	0.518	0.443	0.597	0.543	0.494	0.620

*Note:* This table presents the effect of change feedback and level feedback interacted with students' gender when given 1-3 days in advance using a linear regression model including class fixed effects. Column 1 and 4 present the results for the whole sample, columns 2 and 5 present the results for students whose rank improved from exam 1 to exam 2, and columns 3 and 6 present results for students whose rank worsened from exam 1 to exam 2. The dependent variable in columns 1, 2, and 3 is percentage points in exam 3. The dependent variable in columns 4, 5, and 6 is grades in exam 3 (larger grades are worse grades). Covariates: percentage points exam 1, percentage points exam 2, gender, own room, foreign name. Standard errors are reported in parentheses, clustered at classroom level and corrected using biased-reduced linearization. The number of clusters is 10. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table F.2: CHANGE FEEDBACK vs. LEVEL FEEDBACK vs. CONTROL - Class-Level Treatment: LATE TIMING (Interaction with gender)

	Dep. Var.: Points in Exam 3			Dep. Var.: Grade in Exam 3		
	All	Pos Change	Neg Change	All	Pos Change	Neg Change
Change Feedback	-0.013 (0.030)	-0.004 (0.063)	-0.030 (0.037)	0.210 (0.166)	0.053 (0.413)	0.316 (0.196)
Change Feedback X Female	0.020 (0.062)	0.072 (0.070)	0.006 (0.068)	-0.208 (0.425)	-0.363 (0.466)	-0.036 (0.466)
Level Feedback	-0.014 (0.024)	-0.041 (0.032)	0.018 (0.064)	0.186 (0.191)	0.355 (0.245)	0.020 (0.386)
Level Feedback X Female	-0.017 (0.050)	0.086 (0.075)	-0.073 (0.092)	-0.024 (0.382)	-0.840 (0.523)	0.443 (0.640)
Points Exam 1	0.122 (0.130)	0.094 (0.321)	0.412*** (0.129)	-1.522*** (0.578)	-2.265 (1.487)	-3.014*** (0.779)
Points Exam 2	0.435*** (0.114)	0.433 (0.286)	0.227 (0.141)	-2.790*** (0.491)	-2.057 (1.408)	-1.571** (0.783)
Female	-0.041 (0.030)	-0.104** (0.043)	0.001 (0.060)	0.234 (0.251)	0.588** (0.267)	-0.041 (0.428)
ClassFE	Yes	Yes	Yes	Yes	Yes	Yes
Pupil Controls	Yes	Yes	Yes	Yes	Yes	Yes
<i>N</i>	159	76	83	159	76	83
adj. <i>R</i> <sup>2</sup>	0.353	0.187	0.451	0.386	0.285	0.427

*Note:* This table presents the effect of change feedback and level feedback interacted with students' gender when given immediately before the exam using a linear regression model including class fixed effects. Column 1 and 4 present the results for the whole sample, columns 2 and 5 present the results for students whose rank improved from exam 1 to exam 2, and columns 3 and 6 present results for students whose rank worsened from exam 1 to exam 2. The dependent variable in columns 1, 2, and 3 is percentage points in exam 3. The dependent variable in columns 4, 5, and 6 is grades in exam 3 (larger grades are worse grades). Covariates: percentage points exam 1, percentage points exam 2, gender, own room, foreign name, siblings. Standard errors are reported in parentheses, clustered at classroom level and corrected using biased-reduced linearization. The number of clusters is 9. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

## G Psychological Mechanisms: Math Confidence, Effort-effectiveness Belief, and Self-esteem

Table G.1: CHANGE FEEDBACK vs. LEVEL FEEDBACK vs. CONTROL - Dep. var. math confidence

	(1)	(2)	(3)	(4)	(5)
	All	Pos Change	Neg Change	Boys	Girls
Change Feedback	-0.114 (0.184)	-0.308* (0.182)	0.187 (0.172)	-0.263 (0.222)	-0.210 (0.372)
Level Feedback	0.048 (0.116)	0.050 (0.155)	0.039 (0.261)	-0.276** (0.129)	0.314 (0.260)
Points Exam 1	1.060** (0.487)	1.402 (1.668)	3.171*** (0.855)	1.428* (0.799)	0.709 (0.907)
Points Exam 2	1.285** (0.635)	0.474 (2.926)	-0.567 (1.337)	0.749 (0.774)	1.826** (0.871)
Female	-0.306 (0.196)	-0.271 (0.185)	-0.330 (0.429)		
ClassFE	Yes	Yes	Yes	Yes	Yes
Pupil Controls	Yes	Yes	Yes	Yes	Yes
<i>N</i>	154	84	70	83	71
adj. $R^2$	0.248	0.272	0.223	0.204	0.343

*Note:* This table presents the effect of change feedback and level feedback on state self-esteem of students in early treatment classes using a linear regression model including class fixed effects. Column 1 present results for the whole sample in each early and late treatment classes, column 2 present results for students who improved, and column 3 present results for students who worsened their performance from the second last to the last exam, column 4 presents the results for male students, and column 5 presents the results for female students. Dependent variable: state-self esteem, confidence in mathematics ability (standardized to zero mean and unit standard deviation). Covariates: percentage points exam 1, percentage points exam 2, gender, own room, foreign name, siblings. Standard errors are reported in parentheses, clustered at classroom level and corrected using biased-reduced linearization. The number of clusters is 10. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table G.2: CHANGE FEEDBACK vs. LEVEL FEEDBACK vs. CONTROL - Dep. var. effort-effectiveness belief

	(1) All	(2) Pos Change	(3) Neg Change	(4) Boys	(5) Girls
Change Feedback	0.168* (0.093)	0.274 (0.216)	0.228 (0.182)	-0.048 (0.125)	0.313 (0.255)
Level Feedback	0.017 (0.155)	0.144 (0.216)	-0.065 (0.241)	-0.489** (0.197)	0.478*** (0.160)
Points Exam 1	1.003*** (0.272)	1.693*** (0.618)	0.922 (1.621)	1.069 (0.736)	0.971 (0.601)
Points Exam 2	1.273** (0.559)	0.187 (1.095)	1.259 (1.309)	1.328** (0.626)	0.953 (1.000)
Female	-0.079 (0.118)	-0.147 (0.102)	0.063 (0.262)		
ClassFE	Yes	Yes	Yes	Yes	Yes
Pupil Controls	Yes	Yes	Yes	Yes	Yes
<i>N</i>	161	88	73	84	77
adj. <i>R</i> <sup>2</sup>	0.086	0.119	-0.076	0.189	0.032

*Note:* This table presents the effect of change feedback and level feedback on the effort-effectiveness belief of students in early treatment classes using a linear regression model including class fixed effects. Column 1 present results for the whole sample, column 2 present results for students who improved, column 3 present results for students who worsened their performance from the second last to the last exam, column 4 presents the results for male students, and column 5 presents the results for female students. Dependent variable: effort-effectiveness belief (standardized to zero mean and unit standard deviation). Covariates: percentage points exam 1, percentage points exam 2, gender, own room, foreign name, siblings. Standard errors are reported in parentheses, clustered at classroom level and corrected using biased-reduced linearization. The number of clusters is 10. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table G.3: CHANGE FEEDBACK vs. LEVEL FEEDBACK vs. CONTROL - Dep. var. state self-esteem

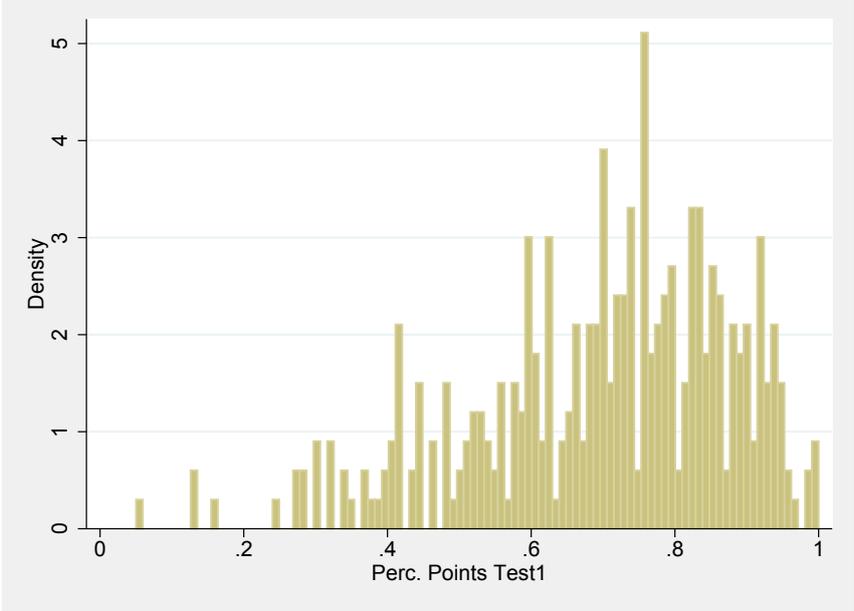
	(1) All	(2) Pos Change	(3) Neg Change	(4) Boys	(5) Girls
Change Feedback	-0.206 (0.130)	-0.437* (0.232)	-0.075 (0.249)	-0.549** (0.270)	0.439* (0.250)
Level Feedback	-0.280* (0.142)	-0.442* (0.232)	-0.058 (0.263)	-0.464*** (0.150)	-0.095 (0.258)
Points Exam 1	0.715 (0.673)	1.593 (0.991)	0.189 (2.276)	0.867 (1.470)	0.771 (0.740)
Points Exam 2	1.507*** (0.535)	0.251 (1.234)	1.640 (1.699)	2.041* (1.143)	0.712 (0.493)
Female	-0.113 (0.168)	-0.011 (0.327)	-0.028 (0.201)		
ClassFE	Yes	Yes	Yes	Yes	Yes
Pupil Controls	Yes	Yes	Yes	Yes	Yes
<i>N</i>	151	81	70	80	71
adj. $R^2$	0.132	0.147	0.056	0.181	0.119

*Note:* This table presents the effect of change feedback and level feedback on state self-esteem of students in early treatment classes using a linear regression model including class fixed effects. Column 1 present results for the whole sample, column 2 present results for students who improved, column 3 present results for students who worsened their performance from the second last to the last exam, column 4 presents the results for male students, and column 5 presents the results for female students. Dependent variable: state-self esteem (standardized to zero mean and unit standard deviation). Covariates: percentage points exam 1, percentage points exam 2, gender, own room, foreign name, siblings. Standard errors are reported in parentheses, clustered at classroom level and corrected using biased-reduced linearization. The number of clusters is 10. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

# Online Appendix

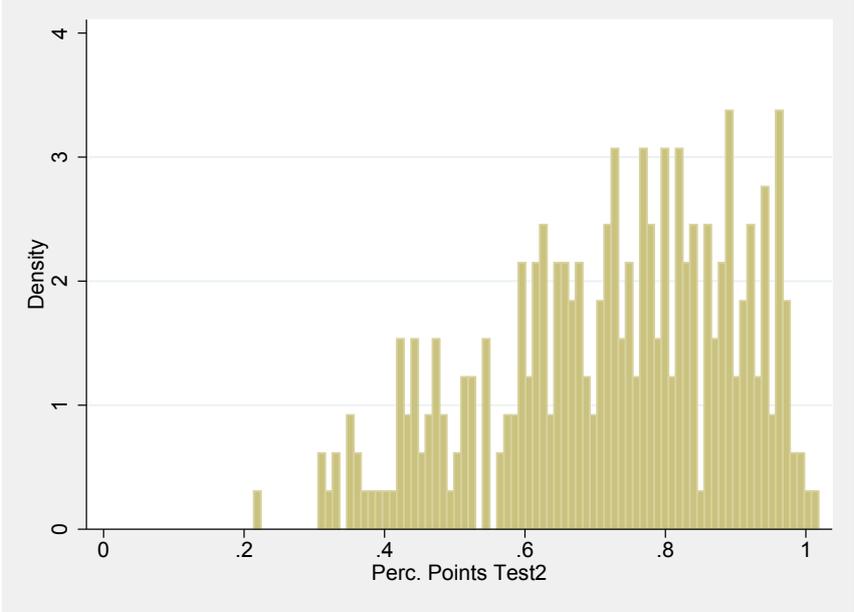
## H Distribution of Points

Figure H.1: Distribution of points in Test 1



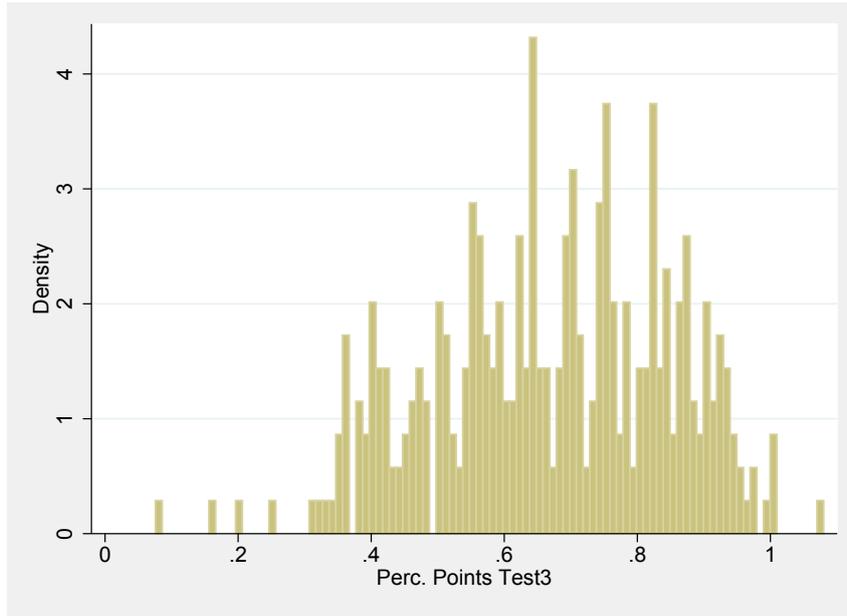
*Note:* This graph shows the distribution of points in test 1.

Figure H.2: Distribution of points in Test 2



*Note:* This graph shows the distribution of points in test 2.

Figure H.3: Distribution of points in Test 3



*Note:* This graph shows the distribution of points in test 3.

## I Illustrative Theoretical Framework

We varied both the type as well as the timing of feedback as we expected that both dimensions might matter for how feedback affects behavior. In the following, we outline why we expected them to matter. We stress, however, that the following exposition is only meant to illustrate possible mechanisms to give guidance on how one could think about the mechanisms of feedback. Thus we will not derive testable hypotheses, as predictions about how feedback affects an agent’s behavior depends on the agent’s prior beliefs as well as what information an agent infers from the feedback. We have some evidence about both aspects, but the field setting we study does not allow us to prove any one mechanism. For this reason, the following model should only be understood to motivate the treatment variation and should otherwise be treated as purely illustrative of the mechanisms by which feedback may affect behavior.

**Effects of Feedback on ability beliefs and emotions** We build on a model by Fischer and Sliwka (2018) and adapt it to our setting in order to illustrate how feedback about levels of performance or feedback about changes in performance may affect effort

and in turn exam outcomes. We assume that a student strives for a certain exam outcome (such as a passing grade or a grade she deems satisfactory) and that how much effort she invests in it depends on (i) confidence in her exam-related prior knowledge and (ii) confidence in the effectiveness of her effort (i.e. in her academic ability) and (iii) on her emotional state.

A risk neutral student can invest effort to raise her knowledge. Her knowledge at the test, which determines her exam outcome, is the sum of prior knowledge  $k$  and knowledge increases due to (learning and test-taking) effort  $\Delta$ . Knowledge acquisition is costly and the student's cost function is

$$c(\Delta, a, p)$$

where  $a$  measures the student's effectiveness of effort and  $p$  measures her emotional state (the pleasure she experiences while exerting effort). It is assumed that  $\frac{\partial c}{\partial \Delta}, \frac{\partial^2 c}{\partial \Delta^2} > 0$  and  $\frac{\partial c}{\partial \Delta \partial a} < 0$  such that the marginal costs of knowledge acquisition are smaller for more academically able students. Furthermore,  $\frac{\partial c}{\partial p} < 0$  such that marginal costs of effort are lower if the student experiences more pleasure from exerting effort (cf. Benabou and Tirole, 2002, 2003, 2016; Köszegi, 2006). The student is uncertain about her prior knowledge  $k$  and the effectiveness of her effort  $a$ . She can receive two types of feedback, the first is a signal about her level of prior knowledge ( $s_k$ ), while the second is a signal about her effectiveness of effort ( $s_a$ ), such that  $\frac{\partial E[a|s_a, s_k]}{\partial s_a} > 0$  and  $\frac{\partial E[k|s_a, s_k]}{\partial s_k} > 0$ . We can decompose  $a = E[a|s_a, s_k] + \varepsilon_{as}$  and  $k = E[k|s_a, s_k] + \varepsilon_{ks}$ . A student's emotional state can be influenced temporarily by the signals she receives: Any good news temporarily raises a student's pleasure from exerting effort in a given situation and any bad news decreases it. Psychologists have found that positive competence feedback (even if it does not contain any information, and thus does not influence expectations) may raise intrinsic motivation by raising enjoyment of the task at hand, while negative (non-informational) feedback may have the opposite effect (Cameron and Pierce, 1994; Deci et al., 1999; Fishbach et al.,

2010). Thus,  $\frac{\partial E[p|s_a, s_k]}{\partial s_a} > 0$ ,  $\frac{\partial E[p|s_a, s_k]}{\partial s_k} > 0$  and  $p = E[p|s_a, s_k] + \varepsilon_{as} + \varepsilon_{ks} + \varepsilon_{as}\varepsilon_{ks}$ <sup>35</sup>

The student has beliefs about both, her prior knowledge ( $\hat{k}$ ) and about the effectiveness of her effort ( $\hat{a}$ ) which are equal to her expectations about  $a$  and  $k$  conditional on the signals she receives:

$$\hat{k} = E[k|s_a, s_k]$$

$$\hat{a} = E[a|s_a, s_k]$$

Furthermore, a student's emotional state is dependent on the two signals:  $\hat{p} = E[p|s_a, s_k]$ .

Students attain their desired exam outcome, if  $k + \Delta$  exceeds a threshold value  $\tau$ . In that case they will receive reward  $B$  (i.e. a satisfactory exam outcome). Students' objective function can thus be denoted as

$$\max_{\Delta} \Pr(\hat{k} + \varepsilon_{ks} + \Delta > \tau) B - E[c(\Delta, a, p)|s_a, s_k].$$

The first derivative of the objective function is

$$g_{\varepsilon_{ks}}(\tau - \hat{k} - \Delta) B - E\left[\frac{\partial c(\Delta, \hat{a} + \varepsilon_a, \hat{p})}{\partial \Delta}\right]$$

where  $g_{\varepsilon_{ks}}$  is the density of the error term associated with the signal  $s_k$ . Under the condition that the objective function is strictly concave, such that it has a unique solution, it can be shown that:

**Proposition** *Effort is strictly increasing in the student's confidence in the effectiveness of her effort  $\hat{a}$  as well as in her intrinsic motivation  $\hat{p}$ . It is strictly decreasing in the student's confidence in prior knowledge  $\hat{k}$  if and only if  $\hat{k}$  is larger than a cut-off value and otherwise strictly increasing.*

The intuition behind this proposition is the following: All students will exert more

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<sup>35</sup>Assume that  $\varepsilon_{as}$  and  $\varepsilon_{ks}$  are uncorrelated with the signals  $(s_a, s_k)$ , have mean zero, and unimodal densities with  $g'_{\varepsilon_{as}}(0) = g'_{\varepsilon_{ks}}(0) = 0$ .

effort when their confidence about their academic ability ( $\hat{a}$ ) or their pleasure from exerting effort ( $\hat{p}$ ) increases as this causes them to perceive their marginal costs of effort to be lower. Benabou and Tirole (2002) call this the “motivation value” of higher confidence. Making students who already perceive their level of prior knowledge as high (relative to their desired outcome) even more confident about it will decrease effort as it makes them only more certain that they do not need to invest more effort to achieve their desired exam outcome. However, raising the confidence in prior knowledge ( $\hat{k}$ ) of students who perceive their prior knowledge to be very low will increase effort as they perceive greater chances that their effort will help them to attain their desired outcome.

### **Effects of feedback on extrinsic and intrinsic motivation**

A student’s desired outcome likely depends on where in the ability distribution within the class she is. If she is very good at math compared to her classmates, she will likely strive for a top grade (i.e. a top position in the ranking), if she is about average she might strive for an average or somewhat above average grade, while if she knows she is rather weak at math she will just strive for a passing grade (i.e. avoiding the last places in the ranking). Giving students level feedback will disappoint those who overestimate their prior performance while it will positively surprise those who underestimate their prior performance. It has often been found that people tend to overestimate their abilities (Camerer and Lovallo, 1999; Park and Santos-Pinto, 2010; Gervais et al., 2011; Grossman and Owens, 2012).<sup>36</sup> We expect that most students will be disappointed by the level feedback they receive. In the short run this will worsen their emotional state and decrease their intrinsic motivation to exert effort but they learn that they need to exert more effort than expected in order to attain their desired outcome which raises their extrinsic motivation to exert effort.

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<sup>36</sup>Students in our sample on average indicate above average confidence: The average student stated that the past two exams were “rather easy” (indicating an average value of 2.2 for both the first and the second test on a scale from 1 to 4, both of which are significantly smaller than 2.5 at the 1%-level (t-test)). The average student also stated they they felt “rather well” prepared for the two past exams (indicating an average value of 2.9 for the first test and 3.0 for the second test on a scale from 1 to 4, both of which are significantly larger than 2.5 at the 1%-level (t-test)). The average student’s confidence in math ability is 0.58 on a scale from 0 to 1, where boys have an average value of 0.61 and girls of 0.55. This is a difference of 0.31 standard deviations, which is significant at the 1%-level (t-test). It is a common finding that males are more confident in their abilities than females (see e.g. Barber and Odean, 2001; Niederle and Vesterlund, 2007). All tests in this paper are two-sided.

Change feedback contains information about how a student's performance changed relative to her classmates from the second last to the last math exam. If we assume that the second last and the last exam measure the same dimension of knowledge, the rank in the second last exam captures prior knowledge with respect to the last exam and the change in rank captures her newly acquired knowledge (her progress) relative to her classmates. If, additionally, students exerted the same amount of effort for the last exam<sup>37</sup> this progress reveals information about the effectiveness of a student's effort relative to her classmates. We thus expect students receiving positive change feedback to have higher confidence in the effectiveness of their effort, which raises extrinsic motivation, as well as higher intrinsic motivation. Students who receive negative change feedback will have lower confidence in the effectiveness of their effort, which decreases extrinsic motivation, as well as lower intrinsic motivation.

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<sup>37</sup>The average student in our sample reported that they felt equally well prepared for the first and second exam (indicating average values of 2.9 for the first and 3.0 for the second test on a scale from 1 to 4, which are not significantly different from each other (t-test)).