The Internet and Higher Education 55 (2022) 100872

Contents lists available at ScienceDirect

The Internet and Higher Education

journal homepage: www.elsevier.com/locate/iheduc

How am I going and where to next? Elaborated online feedback improves university students' self-regulated learning and performance

Maria Theobald [a,*], Henrik Bellhäuser [b,**]

[a] DIPF, Leibniz Institute for Research and Information in Education, Germany
[b] Johannes Gutenberg-University Mainz, Germany

ARTICLE INFO

Keywords:
Feedback
Self-regulated learning
Motivation
Learning diaries

ABSTRACT

The goal of this study was to examine the effects of adaptive online feedback on self-regulated learning, motivation, and achievement. University students ($N = 257$) participated in an experimental field study with an intensive longitudinal design (daily assessment over 30 days). The experiment included a between-subject and a within-subject manipulation. The target of the feedback intervention was varied between subjects: Students either received (1) feedback on metacognitive aspects, (2) feedback on motivational aspects, (3) feedback on metacognitive and motivational aspects, (4) or no feedback. Within the three feedback groups, we additionally varied feedback content from day to day within-subjects. Students either received (1) informative feedback on self-regulated learning (2) directive feedback including only a strategy suggestion, (3) transformative feedback including feedback on self-regulated learning and a strategy suggestion, (4) or – on some days – no feedback. Results revealed that informative, directive, and transformative informative feedback reduced students' procrastination and improved daily self-monitoring, adherence to time schedules, and goal achievement compared to receiving no feedback. Informative and transformative feedback additionally improved planning strategies and concentration. Motivation and self-efficacy were unaffected by any kind of feedback. The positive effects of the intervention were most pronounced when students received feedback on metacognitive and motivational aspects. Moreover, students in the feedback groups achieved better grades in the examinations compared students in the control group. Together, results indicate that the feedback intervention effectively improved students' self-regulated learning and achievement. We discuss differential effectiveness of the feedback depending on feedback content.

1. Introduction

Self-regulated learning (SRL) describes a students' ability to plan, monitor, and regulate cognition, motivation, and behavior to achieve self-set goals (Zimmerman, 2000). SRL is important for university students' academic success: For instance, the competence to self-regulate learning is associated with higher academic achievement (Richardson, Abraham, & Bond, 2012) – especially in online higher education learning environments (Broadbent & Poon, 2015). Further, students with better SRL strategies are more satisfied with their studies (Liborius, Bellhäuser, & Schmitz, 2019), can cope more easily with the transition between school and university (Park, Edmondson, & Lee, 2012), and are less likely to drop their studies (Blüthmann, Thiel, & Wolfgramm, 2011). Hence, SRL constitutes a key competence for university success.

Self-regulated learning is a dynamic and complex process. According to Zimmerman's (2000) cyclical model, SRL subsumes three phases. In the forethought phase, before studying, learners set goals, make plans, and motivate themselves for studying. In the performance phase, during studying, learners monitor their learning progress and apply self-control strategies to maintain task focus and motivation. In the self-reflection phase, after studying, learners evaluate their goal achievement and reflect about their strategy use and motivation: Did I achieve my goals? Which strategies worked well, and which did not? How can I increase my motivation to study next day? That is, learners engage in reflective processes that are assumed to affect the next forethought phase in terms of an internal feedback loop. These internal feedback loops are described in the self-regulation model by Butler and Winne (1995). Learners continually monitor the current state in a task and self-generate internal

* Correspondence to: M. Theobald, DIPF, Leibniz Institute for Research and Information in Education, Rostocker Str. 6, 60323 Frankfurt am Main, Germany.
** Correspondence to: H. Bellhäuser, Johannes Gutenberg-University Mainz, Binger Str. 14-16, 55122 Mainz, Germany.
E-mail addresses: theobald@dipf.de (M. Theobald), bellhaeuser@uni-mainz.de (H. Bellhäuser).

https://doi.org/10.1016/j.iheduc.2022.100872
Received 24 January 2022; Received in revised form 26 June 2022; Accepted 26 June 2022
Available online 30 June 2022

feedback about their goal progress. Ideally, learners use this internal feedback to modify their SRL strategies accordingly. Hence, according to both models, self-regulated learners monitor and self-reflect on their current goal progress (see Panadero, 2017 for a detailed comparison of SRL models). Learners thus generate internal feedback, which they use to control subsequent learning processes.

To monitor and to control learning processes is far from trivial, however. For instance, many students have difficulties in accurately monitoring their own knowledge (Kruger & Dunning, 1999). Further, learners can suffer from availability or production deficiencies in strategy use (Veenman, Van Hout-Wolters, & Afflerbach, 2006). Learners with an availability deficiency lack metacognitive knowledge about effective strategies. Learners with a production deficiency know effective strategies but fail to apply those strategies in a given context. Taken together, learners need to accurately monitor difficulties in strategy application and they need to know and apply effective strategies to overcome those difficulties.

External feedback could help learners to monitor and control their strategy use. According to Hattie and Timperley (2007), effective feedback encompasses three components: feed-up, feed-back, and feed-forward. First, feed-up includes information on goals. For instance, learners are reminded of the task goals. Prior research revealed that making learning goals transparent can improve students' self-regulated learning and self-efficacy (Panadero, Tapia, & Huertas, 2012a; Panadero, Tapia, & Huertas, 2012b). Second, feed-back informs learners about the current state of learning. That is, feed-back provides learners with information about their goal progress relative to their initially set goal, which has been shown to benefit self-monitoring (Wollenschläger, Hattie, Machts, Möller, & Harms, 2016) and learning (Kluger & DeNisi, 1996). Third, effective feedback includes feed-forward that gives learners the possibility to improve their learning (Hattie & Timperley, 2007). For instance, feed-forward could include strategy suggestions. Wollenschläger et al. (2016) showed that feedback that included feed-forward on how to proceed with a task improved learners' monitoring accuracy and self-efficacy most effectively (as compared to a condition that only included feed-up or feed-back). Taken together, effective external feedback could support the internal feedback loop by making goal progress transparent and by providing guidance on how to effectively regulate strategy use. To date, research that tested how the three feedback components (feed-up, feed-back, feed-forward) affect various aspects of self-regulated learning, motivation and performance is scarce. Further, the abovementioned prior research did not examine the effects of individual, automatically generated feedback on students' day-to-day self-regulation. The current study aims to address these gaps by testing whether automatically generated feed-up, feed-back, and feed-forward can improve students' daily self-regulated learning, and motivation.

2. Theoretical background

2.1. Feedback and self-regulated learning

Feedback constitutes a powerful tool to foster learning outcomes. For instance, in their meta-analysis, Wisniewski, Zierer, and Hattie (2020) found that feedback improved cognitive (e.g., academic achievement), motivational (e.g., self-efficacy and persistence), as well as behavioral (e.g., student behavior in the classroom) outcomes. However, feedback effectiveness depended on the type of feedback. Wisniewski et al. (2020) stated that elaborated feedback was more effective compared to corrective feedback, reinforcement feedback or punishment feedback.

These different types of feedback vary in informativeness. For instance, reinforcement or punishment feedback provides limited information about task performance and no information about learning processes or self-regulation. Instead, this type of feedback draws attention to the self, e.g., to students' competences, which has been shown to be less effective (Kluger & DeNisi, 1996; Shute, 2008). Corrective feedback typically includes information on the correct solution of a task. This type of feedback can be effective for learning new skills (Hattie & Timperley, 2007). Elaborated feedback further includes information on students' self-regulation during learning (Shute, 2008; Wisniewski et al., 2020). In their meta-analysis, Kluger and DeNisi (1996) found that elaborated feedback that included information on the gap between intended performance level and actual performance level improved performance. Van der Kleij, Feskens, and Eggen (2015) conducted another meta-analysis on the role of feedback in computer-based learning environments. The authors found that elaborated feedback was most effective if it included feedback on task goals (feed-up), goal progress (feed-back), and regulation (feed-forward). Taken together, results from previous meta-analyses suggest that elaborated feedback that includes information on goals, goal progress, and self-regulation is most effective for improving learning outcomes.

How could elaborated feedback benefit self-regulated learning? First, feedback that provides information on goals (feed-up) and current goal progress (feed-back) could facilitate metacognitive monitoring. In line with this, it has been shown that metacognitive monitoring can be improved by providing repeated feedback with respect to a standard (feed-up) (e.g., Callender, Franco-Watkins, & Roberts, 2016; Nietfeld, Cao, & Osborne, 2006; van Loon & Roebers, 2017). Moreover, explaining students how they can improve their monitoring accuracy (feed-forward) enhanced metacognitive monitoring (Miller & Geraci, 2011; Wollenschläger et al., 2016). These studies mainly focused on the effects of feedback on students' self-monitoring. However, these results did not indicate whether feedback improves other aspects of self-regulated learning, such as planning strategies, concentration, or motivation. Furthermore, to the best of our knowledge, there are no prior studies that tested how the three components of elaborated feedback (feed-up, feed-back, feed-forward) may affect various aspects of students' self-regulated learning and motivation from one study day to the next. Thus, it is unclear which feedback components are needed to effectively improve self-regulated learning and motivation in daily life.

Second, feedback could help students to apply SRL strategies. A recent meta-analysis revealed that feedback boosted SRL training effects (Theobald, 2021). That is, SRL training programs that included teacher feedback (vs. no teacher feedback) improved students' use of metacognitive strategies and resource-management strategies. Feedback further enhanced training effects on students' motivation. Feedback could, thus, help students to acquire SRL strategies and to increase their motivation to apply those strategies. In sum, prior findings suggest that feedback can improve students' metacognitive monitoring, SRL strategy use, and motivation. However, research that has examined the effects of feedback on self-regulated learning – particularly in authentic daily learning situations – is yet missing.

2.2. Fostering students' SRL in daily life

How could SRL be improved in daily life? SRL can vary from one study session to the next, which calls for adaptive intervention approaches (Bellhäuser, Mattes, & Liborius, 2021; Theobald, Bellhäuser, & Nückles, 2019). For instance, learning diaries that require students to report their daily SRL strategies and motivation could help students to monitor their SRL. However, monitoring SRL alone does not suffice to improve strategy use. For instance, a range of studies showed that learning diaries that ask students to report and reflect on their strategy use did not improve SRL (Bellhäuser, Lösch, Winter, & Schmitz, 2016; Broadbent, Panadero, & Fuller-Tyszkiewicz, 2020; Dörrenbächer & Perels, 2016). Learning diaries only improved SRL if they included study advices (Dignath, Fabriz, & Büttner, 2015), or strategy prompts (Cheng, 2017; Loeffler, Bohner, Stumpp, Limberger, & Gidion, 2019). These results suggest that learning diaries were only effective if they were combined with strategy instruction. Otherwise, students might realize that they don't effectively regulate their studying but don't know appropriate strategies to change their study approach. This mismatch may explain why learning diaries sometimes even reduce students'

motivation (Dörrenbächer & Perels, 2016). Together, these studies suggest that learning diaries could improve SRL but only if combined with strategy instruction.

In summary, feedback could augment the effects of learning diaries on SRL. Learning diaries encourage students to set goals and to generate internal feedback on their goal achievement. External feedback could support this reflection by providing information on goals (feed-up) and current goal progress (feed-back). Learning diaries alone, however, hardly provide guidance on how to change SRL strategies to improve learning. Therefore, strategy suggestions (feed-forward) could help students to successfully adapt SRL strategies. Feedback could, thus, boost the effectiveness of learning diaries to improve SRL by facilitating self-monitoring and strategy regulation. However, to date, research on the effects of adaptive feedback on daily reported SRL is largely missing.

2.3. The present study

Feedback loops are an integral part in SRL as students continually generate internal feedback on their learning progress. This study tested whether external, adaptive feedback can enhance daily SRL. We systematically varied the provision of feed-back and feed-forward in an experimental field study using fine-grained daily state measures of SRL. The first aim is to disentangle the effect of feed-back and feed-forward on daily SRL using a within-subject manipulation of these two feedback components. That is, participants alternately received either (1) informative feedback, which only included feed-back, (2) directive feedback, which only included feed-forward, (3) transformative feedback, which included feed-back and feed-forward, (4) or, on some days, they received neither feed-back nor feed-forward. Based on previous literature on the effectiveness of feedback (Hattie & Timperley, 2007; Wollenschläger et al., 2016), we hypothesized that informative feedback that makes goals and goal progress transparent does not suffice to improve self-regulated learning. Learners might realize that they did not achieve their study goals but do not know how to change their learning strategies. Therefore, the provision of concrete strategy suggestions is assumed to be crucial to promote learning. Hence, we hypothesized that:

H1. Students report better SRL if they received transformative feedback (feed-back and feed-forward) on the previous day compared to receiving no feedback, or only informative feedback without receiving a strategy suggestion.

The second research aim concerns the target of feedback. As a between-subject manipulation, we varied the target of the feedback intervention. The feedback intervention either focused on (1) metacognitive aspects, (2) motivational aspects, (3) or the combination of metacognitive and motivational aspects. Doing so, we were able to test whether feedback effectiveness varied depending on the target of the feedback. We hypothesized that:

H2a. Feedback on metacognitive aspects of learning improves metacognitive strategy use (better planning and self-monitoring and lower procrastination) over the course of the study compared to receiving no feedback.

H2b. Feedback on motivational aspects improves students' motivation (study motivation and self-efficacy) and effective motivation regulation (concentration) over the course of the study compared to receiving no feedback.

H2c. Feedback on metacognitive and motivational aspects improves both, metacognitive strategy use and motivation, over the course of the study compared to receiving no feedback.

Taken together, this study adds to prior research on feedback and self-regulated learning in three ways. First, prior research (e.g., Callender et al., 2016; Miller & Geraci, 2011; Nietfeld et al., 2006; van Loon & Roebers, 2017; Wollenschläger et al., 2016) mainly focused on self-monitoring as an outcome variable, but did not test whether feedback improves other aspects of self-regulated learning as well, such as planning strategies, concentration, or motivation. Second, these prior studies did not test how the three components of elaborated feedback (feed-up, feed-back, feed-forward) may differentially affect students' self-regulated learning, motivation, and performance. The present study therefore contributes to the question of which components make feedback most effective. Third, in the present study we tested the effectiveness of feedback in an authentic learning setting using fine-grained daily state measures of students' daily self-regulated learning. This way we could examine short- and longer-term effects of feedback with high ecological validity. Students thereby completed learning diaries online and received automated feedback on their entries, which has not been done in prior studies. From a practical point of view, this study thus adds to the question how teachers can provide fast and timely feedback to individual students.

3. Methods

3.1. Transparency and openness

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study. Research questions, hypotheses, and methods were preregistered via the Open Science Framework (OSF) prior to conducting the study (Link to preregistration: https://osf.io/r86kb). The OSF project further contains the data used for data analysis, the data analysis code including the code for power simulation, and an overview on questionnaire items, learning diary items, and feedback (Link to project: https://osf.io/rdwc2/). Data and materials will be made available on OSF upon publication. All analyses were conducted in R (R Core Team, 2019).

3.2. Participants

Initially, 257 students from a large university in Germany registered for the study. We used the MLPowSim software package (Browne, Lahi, & Parker, 2009) to estimate the target sample size[1] ($n = 240$ subjects on level 2, $k = 30$ days on level 1) with the following settings: standardized beta for feedback effect = 0.07, $\alpha = 0.05$, $\beta = 0.85$. The starting values for the simulation were determined based on the results from a pilot study in which we tested the effects of a simplified version of the feedback intervention (Theobald, 2019). We recruited more students than the target sample size to account for potential dropout.

Students registered for the study online if they were preparing for an exam during the 30-day daily survey period. Study procedures were in accordance with the APA ethical principles. Before registering for the study, students were informed about the study purpose, duration, and procedures and gave their informed consent. Students were randomly assigned to one of 4 groups (see between-subject manipulation below): Metacognitive feedback ($n = 61$), motivational feedback ($n = 61$), metacognitive and motivational feedback ($n = 62$), and a control group without feedback ($n = 61$). We excluded 13 subjects who did not respond to any of the learning diaries. Wilkoxon tests revealed that dropouts were comparable to participants who participated in the study regarding gender ($W = 1177$, $p = .580$), age ($W = 986$, $p = .633$), semester ($W = 1181$, $p = .563$), as well as SRL strategies and motivation reported before the beginning of the 30-day daily survey period (planning and goal setting: $W = 1164$, $p = .626$, time management strategies: $W = 1138$, $p = .186$, self-monitoring: $W = 1173$, $p = .596$,

[1] Note that the target sample size differs from the sample size reported in the preregistration. The preregistration was published before we finalized data analysis from the pilot study. Based on the pilot data, we decided to recruit more participants to have sufficient power to detect the effects of the feedback intervention. Importantly, we decided to change the target sample size before starting data collection.

procrastination: $W = 967.5$, $p = .652$, self-efficacy: $W = 911$, $p = .470$, and self-motivation: $W = 1015.5$, $p = .825$).

Participants ($N = 244$) were on average 22 years old ($M = 21.98$, $SD = 2.28$, [18; 31]; 74% female), studied in their fourth semester ($M = 3.68$, $SD = 2.24$, [1; 10]), and came from various fields of study, i.e., teacher training (31%), economics and political science (26%), natural sciences (17%), humanities and social sciences (13%), and languages and cultural studies (13%).

3.3. Procedure and design

Fig. 1 and Fig. 2 provide an overview of the experimental design. Students completed a pre-questionnaire, daily learning diaries over the course of 30 days, and a post-questionnaire. For the 30-day daily survey period, students were randomly assigned to one of four experimental conditions, which are described in more detail below (see Between-subject manipulation). The experiment was conducted online using

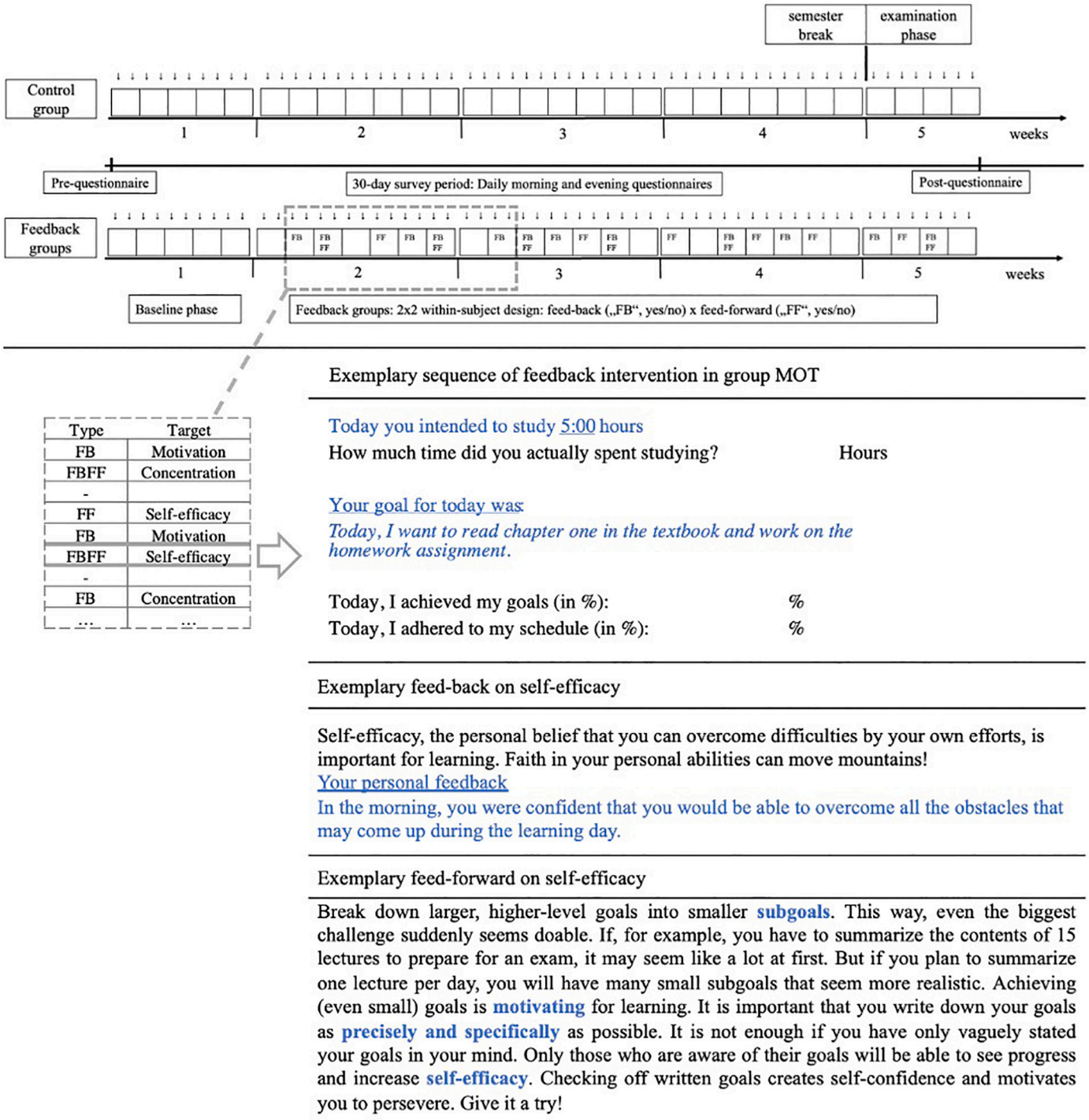

Fig. 1. Study design.

Note. The figure provides an overview of the survey period and feedback design. The upper part of the figure shows the overall design of the study. Students in all groups answered a morning and an evening questionnaire over the course of 30 days denoted by two arrows (↓) per box. After a baseline phase, the feedback groups either received (1) only feed-back ("FB"; so-called *informative* feedback), (2) only feed-forward ("FF", so-called *directive* feedback), (3) feed-back and feed-forward ("FBFF", so-called *transformative* feedback), or (4) neither feed-back nor feed-forward. The control group never received any kind of feedback.

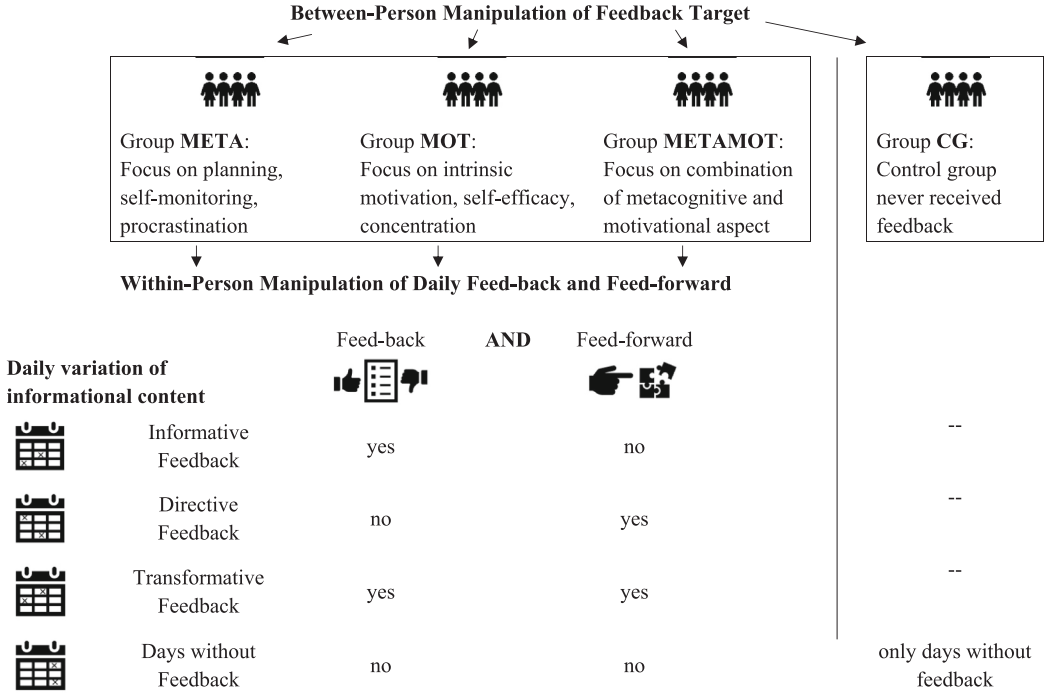

Fig. 2. Overview between- and within-person manipulation.

SoSci Survey (Leiner, 2019).

3.4. Pre-questionnaire

Students first completed a pre-questionnaire. In the pre-questionnaire, students filled in a demographic questionnaire and reported their general use of SRL strategies and motivation. Items were taken from established questionnaires (Procrastination Questionnaire for Students; Glöckner-Rist, Engberding, Höcker, & Rist, 2014; Professional self-efficacy; Schyns & Collani, 2014; Learning Strategies for Students, Wild & Schiefele, 1994). Exemplary items for each scale are shown in Table 1. A detailed overview on the questionnaires is available via OSF (https://osf.io/rdwc2/). Descriptive statistics and intercorrelations between the scales are provided in the supplementary materials (see Supplementary Table 1).

3.5. Daily learning diary

Throughout the 30-day survey period (running 30 days from 18th of June until 17th of July 2019), all students filled in daily electronic learning diaries that comprised a morning and an evening questionnaire (see Fig. 1). Students received daily e-mail invitations to fill in the morning and evening questionnaire respectively. The daily questionnaire items were developed based on the respective pre- and post-questionnaires listed above. The daily items have been adapted to refer to daily activities (see Table 1; a detailed overview of all items is provided on OSF: https://osf.io/rdwc2/).

In the morning questionnaire, students reported their learning goals and intended time investment in an open text field. Students then reported their planning strategies (ICC = 0.41), self-efficacy (ICC = 0.38), and study motivation (ICC = 0.51). In the evening questionnaire students reported their monitoring strategies (ICC = 0.33), procrastination (ICC = 0.22), and concentration (ICC = 0.23). Students further reported their goal achievement ("Today, I achieved my goals."; ranging from 0 to 100%, ICC = 0.21) and whether they adhered to their time schedule ("Today, I stuck to my schedule."; ranging from 0 to 100%, ICC = 0.21). The intraclass correlations (ICC) indicate a substantial amount of variance on the daily level for all diary scales. The daily measures correlated with the corresponding measures from the pre-questionnaire indicating validity of the scales (see Supplementary Table 1).

3.6. Experimental design

The present study included two experimental manipulations: a between-subject and a within-subject manipulation.

3.6.1. Between-subject manipulation

For the 30-day survey period, students were randomly assigned to one of four groups: no feedback control (CG), metacognitive feedback (META), motivational feedback (MOT), metacognitive and motivational feedback (METAMOT) (see Fig. 2). Students remained in their assigned experimental group throughout the whole experiment. Group CG filled in the daily learning diaries without receiving feedback on their diary entries. Students in the three feedback groups (META, MOT, METAMOT) received automated feedback in the evening questionnaire throughout the 30-day daily survey period. The feedback groups, however, differed in the feedback target: Group META received feedback on their metacognitive strategies and outcomes, i.e., planning, self-monitoring, and procrastination throughout the 30-day survey period. Group MOT received feedback on their self-reported motivation and motivation regulation, i.e., self-efficacy, intrinsic motivation, and concentration throughout the 30-day survey period. Group METAMOT received feedback on both, their metacognitive strategies and motivation throughout the 30-day survey period. Hence, this between-subject manipulation served to test the effectiveness of the feedback intervention (compared to a control group) and it served to test whether the effectiveness of the feedback intervention depends on feedback target.

3.6.2. Within-subject manipulation

Within the feedback groups, we manipulated the informational content of the feedback using a two (feed-back vs. no feed-back) by two (feed-forward vs. no feed-forward) within-subject design. That is, we manipulated on a daily basis whether students received *informative* feedback (i.e., only feed-back), *directive* feedback (i.e., only feed-

Table 1
Exemplary questionnaire items from pre-questionnaire and daily learning diary.

Construct	Exemplary items	Reliability (ω)
Planning and goal setting strategies	*Pre-questionnaire* (6 items): I set learning goals, which then guide my learning.	0.89
	Daily diary (3 items): Today, I have a concrete plan for how far I want to get with my learning.	0.85
Self-efficacy	*Pre-questionnaire* (9 items): I have a solution for every problem in my studies.	0.91
	Daily diary (3 items): Today I am convinced that I will master difficulties while studying.	0.91
Motivation	*Pre-questionnaire* (3 items): I really enjoy what I study.	0.82
	Daily diary (4 items): Today, I learn because I enjoy the content.	0.96
Self-monitoring	*Pre-questionnaire* (6 items): I ask myself questions about the material to make sure I understand everything.	0.83
	Daily diary (3 items): Today, when I was studying, I made sure I understood everything.	0.81
Procrastination	*Pre-questionnaire* (8 items): Today, I put off finishing a task.	0.94
	Daily diary (3 items): Today, I have a concrete plan for how far I want to get with my learning.	0.78
Concentration	*Pre-questionnaire* (6 items): When I study, I am not concentrated.	0.95
	Daily diary (3 items): Today, I got distracted while studying.	0.93
Time management	*Pre-questionnaire* (4 items): I schedule my study times.	0.84
	Daily diary (1 item; assessed in %): Today, I stuck to my schedule.	

Note. All scale items were assessed on a six-point Likert scale ranging from "not true" to "true". The post-questionnaire encompassed the same items as in the pre-questionnaire. For the daily measures, within-subject ω is reported as a measure of reliability. The complete list of questionnaire items from the pre- and post-questionnaire as well as the daily learning diary are available via the Open Science Framework (https://osf.io/rdwc2/).

forward), *transformative* feedback (i.e., feed-back and feed-forward), or – on some days – no feedback (see Figs. 1 & 2).

Feed-back encompassed information on students' self-set study goals and time goals (see Fig. 1, Table 2). In addition, depending on the group assignment (see above), students received written feedback on their metacognitive strategies (group META), motivation (group MOT), or both (group METAMOT). For instance, students in group META received feed-back on one of three potential metacognitive aspects (either planning, self-monitoring, or procrastination in alternate sequence). Students in group MOT received feed-back on one out of three potential motivational aspects (either self-efficacy, intrinsic motivation, or concentration in alternate sequence). Students in group METAMOT received feed-back on a combination of one metacognitive and one motivational aspect (either planning and concentration, self-monitoring and motivation, or procrastination and self-efficacy in alternate sequence).

Feed-back was generated and provided automatically based on students' self-reports on the respective scales. That is, students received either confirming or corrective feedback depending on their average value on a particular scale. Based on a pilot study (Theobald, 2019), we set a cutoff of 4: Students who had an average value equal or above 4 on a particular scale received confirming feedback for this scale while students who had an average below 4 on a particular scale received corrective feedback for this scale. For instance, if a student indicated high average values for self-efficacy (i.e., average self-efficacy of 4 or more on a 6-point scale), confirming feedback was displayed, which informed students that their self-efficacy was high today (see Table 2). If a student indicated low average values for self-efficacy (i.e., average self-efficacy below 4 on a 6-point scale), corrective feedback was displayed, which informed students that their self-efficacy was rather low today (see Table 2). The formulation of the feedback sentences was further slightly varied depending on students self-rated goal achievement. For instance, if students indicated low self-efficacy in the morning but reported that they had achieved their goals in the evening, they received the following feed-back: "*In the morning you still doubted whether you will really make progress in learning today. As you can see, you learning worked well today. So, you can trust a little more in your abilities!*". We followed theoretical considerations for designing effective feedback

Table 2
Exemplary confirmative and corrective feedback and feedforward for each target variable.

Target	Exemplary feedback	Feedforward
Planning strategies	*Confirming feedback*: "Your careful planning in the morning paid off and contributed to your learning success."	Students were suggested to make a timetable, set priorities, and include buffer time.
	Corrective feedback: „In the morning you did not plan your day carefully, which impaired today's studying."	
Self-efficacy	*Confirming feedback*: "In the morning, you were confident that you would be able to overcome obstacles that may come up during the learning day."	Students were suggested to divide larger goals into subgoals.
	Corrective feedback: „In the morning, you were not very confident that you would be able to overcome obstacles that may come up during the learning day."	
Motivation	*Confirming feedback*: "In the morning, you were highly motivated and it was not difficult for you to start studying."	Students were instructed how they can set mastery goals.
	Corrective feedback: „In the morning, your motivation was low, which made it difficult to study efficiently."	
Self-monitoring	*Confirming feedback*: "While learning, you always had your goals in mind and pursued them consistently."	Students were suggested to reflect on their goal progress and to test their understanding of the learning materials.
	Corrective feedback: „While learning, you did not consciously think about your goals and learning progress."	
Procrastination	*Confirming feedback*: "Today, you completed the tasks on your to-do list without much delay."	Students were instructed how to set SMART goals.
	Corrective feedback: „Today, you have partly put off the tasks on your to-do list."	
Concentration	*Confirming feedback*: "Today you were focused while studying and rarely distracted."	Students were suggested to make if-then plans.
	Corrective feedback: „Today you were sometimes distracted and unconcentrated while studying."	

Note. Feedback was adaptive. That is, feedback depended on students' self-reported self-regulated learning and motivation. If students reported high values on a respective scale (i.e., average value of 4 or more on a 6-point scale) confirming feedback was provided. If students reported low values on a respective scale (i.e., average value below 4 on a 6-point scale) corrective feedback was provided.

(Hattie & Timperley, 2007; Kluger & DeNisi, 1996). That is, feedback should be encouraging and focus the learner's attention on the learning process. For this study, the specific content of the written feed-back was designed by the authors and it was similar to the formulation of the respective scale items. We used the item formulation for each scale to generate confirming or corrective feedback. As it would be too extensive to describe all possible feed-back sentences, we provide exemplary confirming and corrective feed-back for each target variable in Table 2. An exemplary description of feed-back and feed-forward on self-efficacy is also provided in Fig. 1.

Feed-forward included short strategy suggestions. Strategy suggestions targeted metacognitive strategies or motivational aspects depending on the group assignment (META vs. MOT vs. METAMOT, see above). For instance, to improve self-efficacy students received the suggestion to divide their goals in smaller subgoals (see Fig. 1). A general overview on the strategy suggestions is provided in Table 2.

Please note that a detailed overview of all potential feed-back sentences, details on the rules of generating feed-back, as well as an overview of the feed-forward can be accessed via OSF (https://osf.io/rdwc2/).

3.7. Post-questionnaire

After the 30-day daily survey period, students were asked to answer a post-questionnaire. In the post-questionnaire, students reported their general SRL strategies and motivation (see pre-questionnaire). Further students were asked to report the grades from the examinations they were preparing for throughout the 30-day daily survey period. As not all students already received their grades at this point, we sent out two additional reminder e-mails. Doing so, we obtained at least one grade from 50% of participants (approximately evenly distributed across conditions: group CG: $n = 37$, group META: $n = 25$, group MOT: $n = 23$, group METAMOT: $n = 32$). Note that students who reported at least one grade did not differ from students who did not report grades regarding age, gender, prior high school GPA, SRL strategies, or motivation (all p-values $> .05$).

Students who completed the pre- and post-questionnaire and completed at least 24 out of 30 learning diaries (80%) received €50 for their participation. On average, participants completed 21 out of 30 diary entries ($M = 21.28$, $SD = 8.37$, [1; 30]). As the number of complete diary entries strongly varied between participants, we controlled for the number of completed diary entries in our data analyses.

3.8. Data analysis

In a first step, we excluded non-study days. We asked participants in the morning if they were planning to study on that day. If they did not intend to study on a given day, they received an alternative diary in which they were asked about their leisure activities. These data points were excluded from data analysis ($k = 979$; 13% of the data). Further, students reported in the evening questionnaire whether they had actually studied that day. If not, they were asked about their leisure activities on that day. These data points were also excluded from data analysis ($k = 1862$; 25% of the data, which corresponds to approximately 2 off-days a week). We further asked students at the end of the evening questionnaire whether they had answered the questionnaire conscientiously. We excluded data points when students indicated that they did not answer the questionnaire conscientiously ($k = 93$; 1% of the data).

We conducted multilevel regression analysis (days clustered within participants) to test the effects of feedback on daily self-regulated learning. The multilevel regression analysis accounts for the fact that each participant provided multiple datapoints (i.e., learning diaries over 30 days). Furthermore, we accounted for autocorrelation, which occurs when data points that are closer in time are more similar than data points that are further away from each other (Bolger & Laurenceau, 2013). Autocorrelation leads to an underestimation of within-subject variability, which can result in biased standard errors and overly liberal tests of significance (Bliese & Ployhart, 2002). For this purpose, we specified a first-order autoregressive error structure to account for the correlation between adjacent measurement points of a participant. Significance levels were set at 0.05 throughout the analyses. We tested our pre-registered hypotheses using one-sided tests.

The multilevel regression analysis served to test the effects of the within-subject manipulation. According to H1, we hypothesized that students would report better SRL if they received transformative feedback on the previous day compared to receiving no feedback or only informative feedback, which did not include a strategy suggestion. To examine this hypothesis, we tested the effects of informative feedback (only feed-back), directive feedback (only feed-forward), and transformative feedback (feed-back and feed-forward) compared to control days (without feed-back and feed-forward) on next day's SRL and motivation. To do so, we included dummy variables for feed-back, feed-forward, and the combination of feed-back and feed-forward as predictors of next day's motivation, self-efficacy, planning strategies, self-monitoring, concentration, procrastination, goal achievement, and adherence to time schedule. We thus tested the effects of informative, directive, and transformative feedback compared to receiving no feedback (the intercept). We conducted the analysis once including and once excluding data from the control group as the procedure was not clearly stated in the preregistration. When including the control group, the intercept also included no feedback days from the control group that never received feedback. As both analyses led to the same conclusions, we included data from the control group to increase statistical power. We further included a dummy variable in each analysis that indicates whether feed-back and feed-forward targeted the respective dependent variable. This way, we tested whether informative, directive, and transformative was especially effective if it targeted the respective dependent variable.

In a second analysis step, we tested the effects of the between-subject manipulation, i.e., whether feedback effectiveness varied depending on the target of the feedback (focus on metacognitive and/or motivational aspects). According to H2, we hypothesized that feedback on metacognitive aspects of learning would especially improve metacognitive strategy use while feedback on motivational aspects of learning would especially improve students' study motivation. The combination of metacognitive and motivational feedback should improve both, metacognitive strategy use and study motivation. We did not specify a directed hypothesis whether the feedback target would differentially affect daily adherence to time schedule and goal achievement. To test H2, we compared the four groups with respect to their average reported motivation, self-efficacy, planning strategies, self-monitoring, concentration, procrastination, adherence to time schedule, and goal achievement over the course of the 30-day daily survey period. These analyses served to test the overall effects of the three feedback types compared to the control condition. In addition, we tested whether the feedback intervention improved students' exam grades. As we did not pre-register this hypothesis, this analysis should be considered explorative. We further tested whether students self-reported SRL and motivation changed from the pre- to the post-questionnaire. These analyses served to test whether the feedback intervention affected more stable aspects of motivation and general SRL strategy use.

4. Results

4.1. Within-subject effects of informative, directive, and transformative feedback

In support of H1, we tested the effects of the within-subject manipulation. That is, we tested whether receiving informative feedback (i.e., only feed-back), directive feedback (i.e., only feed-forward), or transformative feedback (i.e., feed-back and feed-forward) improved next day's SRL and motivation compared to receiving no feedback. This

Table 3
Effects of feed-back and feed-forward (on day t) on SRL and motivation (on day t + 1).

Dependent variable (assessed in the morning)						
	Planning		Self-efficacy		Motivation	
	Estimates [CI]	*p*	Estimates [CI]	*p*	Estimates [CI]	*p*
(Intercept)	4.41 [4.31, 4.51]		4.41 [4.33, 4.50]		3.51 [3.44, 3.58]	
Fixed effects						
Predictors						
Level 2 (between)						
# Learning diaries	< 0.01 [−0.06, 0.07]	0.911	0.01 [−0.05, 0.07]	0.633	−0.05 [−0.12, 0.01]	0.117
Trait dependent variable	0.19 [0.10, 0.27]	< 0.001	0.17 [0.08, 0.25]	< 0.001	0.21 [0.11, 0.31]	< 0.001
Level 1 (within)						
Informative feedback	0.04 [0.01, 0.07]	0.011	0.02 [−0.01, 0.05]	0.221	−0.02 [−0.05, 0.00]	0.163
Directive feedback	0.03 [0.00, 0.06]	0.062	0.03 [0.00, 0.06]	0.080	< 0.01 [−0.03, 0.02]	0.954
Transformative feedback	0.04 [0.01, 0.07]	0.019	0.03 [0.00, 0.06]	0.092	−0.02 [−0.04, 0.01]	0.395
Informative feedback target-specific feedback*	0.01 [−0.03, 0.02]	0.651	0.01 [−0.01, 0.03]	0.388	<−. 01 [−0.03, 0.01]	0.689
Directive feedback target-specific feedback*	0.01 [−0.02, 0.02]	0.724	0.01 [−0.02, 0.04]	0.820	−0.01 [−0.03, 0.00]	0.175
Transformative feedback target-specific feedback*	0.01 [−0.02, 0.03]	0.716	0.01 [−0.02, 0.02]	0.990	−0.01 [−0.03, 0.01]	0.341
Random effects						
Intercept variance	0.44		0.32		0.21	
Residual variance	0.72		0.59		0.23	
R^2	0.04		0.03		0.05	
Dependent variable (assessed in the evening)						
	Self-monitoring		Procrastination		Concentration	
	Estimates [CI]	*p*	Estimates [CI]	*p*	Estimates [CI]	*p*
(Intercept)	4.07 [3.97, 4.16]		3.50 [3.41, 3.60]		3.73 [3.63, 3.82]	
Fixed effects						
Predictors						
Level 2 (between)						
# Learning diaries	0.03 [−0.03, 0.09]	0.351	−0.06 [−0.11, −0.01]	0.021	0.03 [−0.02, 0.08]	0.292
Trait dependent variable	0.18 [0.10, 0.26]	< 0.001	0.17 [0.11, 0.24]	< 0.001	0.22 [0.16, 0.29]	< 0.001
Level 1 (within)						
Informative feedback	0.08 [0.05, 0.11]	< 0.001	−0.05 [−0.08, −0.02]	0.015	0.04 [0.01, 0.08]	0.019
Directive feedback	0.05 [0.03, 0.08]	0.001	−0.05 [−0.08, −0.02]	0.002	0.03 [0.00, 0.06]	0.132
Transformative feedback	0.05 [0.02, 0.08]	0.001	−0.05 [−0.08, −0.02]	0.005	0.05 [0.01, 0.08]	0.025
Informative feedback target-specific feedback*	0.01 [−0.03, 0.02]	0.603	−0.01 [−0.03, 0.04]	0.506	0.01 [−0.01, 0.04]	0.535
Directive feedback target-specific feedback*	0.01 [−0.02, 0.02]	0.632	−0.01 [−0.03, 0.02]	0.758	0.01 [−0.02, 0.03]	0.882
Transformative feedback target-specific feedback*	0.01 [−0.03, 0.02]	0.624	−0.02 [−0.04, 0.01]	0.121	0.02 [−0.01, 0.04]	0.187
Random effects						
Intercept variance	0.33		0.27		0.27	
Residual variance	0.82		1.39		1.36	
R^2	0.04		0.04		0.06	

Note. Regression weights are standardized. Predictors on level 2 are grand-mean-centered. Trait dependent variable refers to the corresponding trait measure that was assessed before the survey period had started, i.e., general planning strategies, self-efficacy, study motivation, self-monitoring, procrastination, and concentration. Informative feedback included only feed-back. Directive feedback included only feed-forward. Transformative feedback included feed-back and feed-forward. Target-specific feedback means that informative, directive, and transformative feedback targeted the respective dependent variable. The interaction thus tested whether informative, directive, or transformative feedback was especially effective when it targeted the respective dependent variable.

analysis served to test H1 that receiving transformative feedback would be more effective compared to receiving only informative feedback or no feedback at all. Results of the multilevel regression analyses are reported in Table 3. Fig. 3 graphically shows the change in SRL and motivation on day $t + 1$ after receiving informative, directive, or transformative feedback on day t compared to receiving no feedback.

Results revealed that receiving informative or transformative feedback improved planning strategies, self-monitoring, concentration, and reduced procrastination on the next study day compared to days without feedback. Receiving directive feedback only improved self-monitoring and reduced procrastination. Students' self-efficacy and motivation were not affected by any kind of feedback. Partly in line with our hypothesis H1, transformative feedback, i.e., the combination of feed-back and feed-forward, improved students' SRL strategies and reduced procrastination on the next study day. However, in contrast to our hypothesis that transformative feedback would be most effective, informative feedback also improved students' SRL strategies and reduced procrastination – even if no strategy suggestion was provided. Descriptively, the effects of informative feedback were even larger than the effects of transformative feedback (except for procrastination, see Fig. 3), but these differences were not statistically significant. Further, there were no target-specific effects (see Table 3). In other words, informative and transformative feedback improved planning strategies, self-monitoring, and concentration as well as reduced procrastination even if feed-back and feed-forward did not explicitly target the respective component.

4.2. Between-subject effects of metacognitive and motivational feedback target

To test the effects of between-subject manipulation, we compared average-reported SRL strategies and motivation of the three feedback

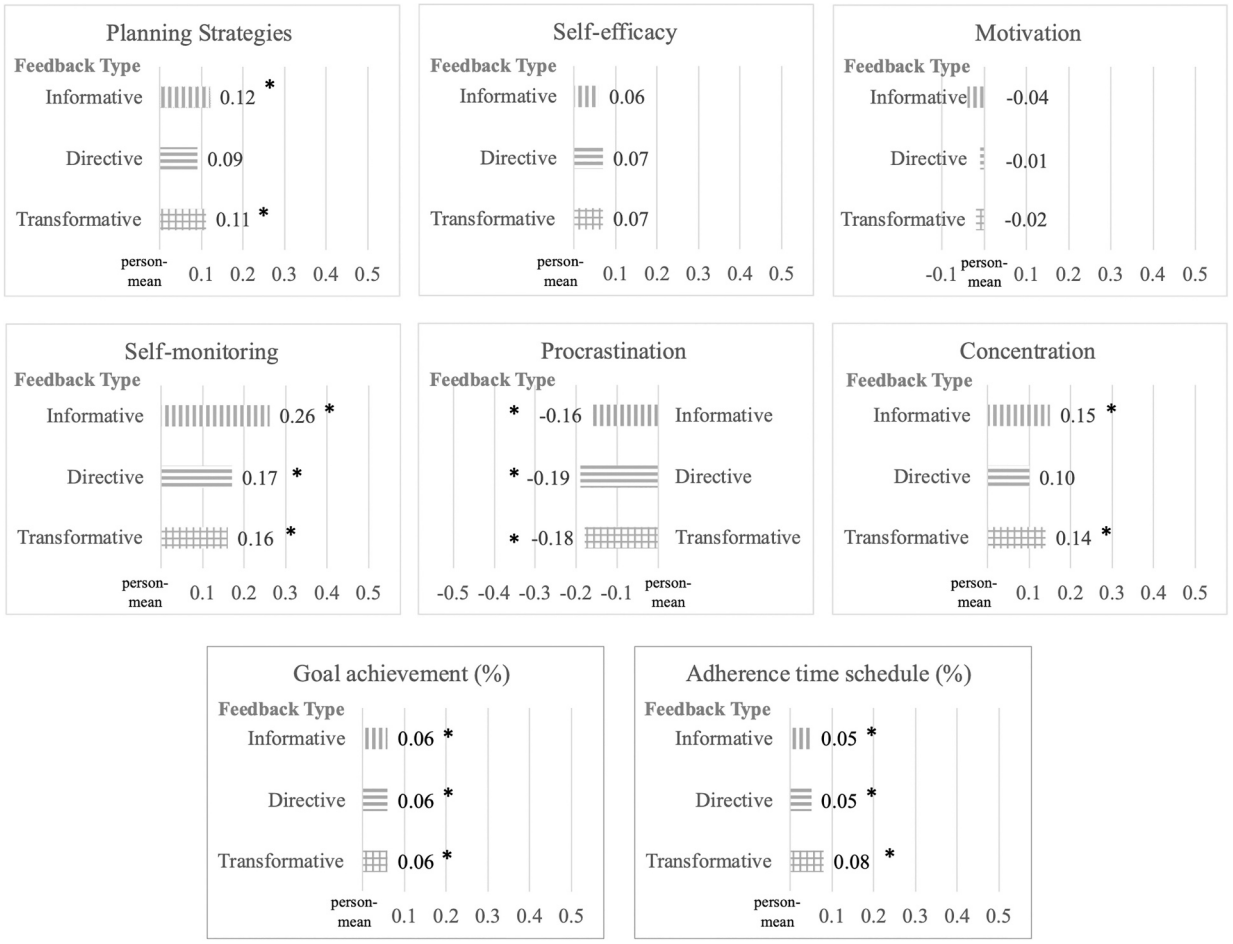

Fig. 3. Effects of informational, directive, and transformative feedback.
Note. The figure shows the change in SRL and motivation on day t + 1 after receiving informative feedback (i.e., only feed-back), directive feedback (i.e., only feed-forward), or transformative feedback (i.e., feed-back and feed-forward) on day t compared to the person-mean-centered value on no feedback days.
* Denotes that increase is statistically significant ($p < .05$).

groups (META, MOT, METAMOT) against the control group (CG). This analysis served to test H2 that (H2a) feedback on metacognitive aspects of learning (group META) would especially improve metacognitive strategy, (H2b) feedback on motivational aspects of learning (group MOT) would especially improve students' study motivation, and (H2c) the combination of metacognitive and motivational feedback (group METAMOT) would improve both, metacognitive strategy use and study motivation.

In a first step, we tested whether there were any differences in self-reported SRL and motivation between groups during the baseline phase at the beginning of the survey period (see Fig. 1). This way, we tested whether there were any group differences before the start of the intervention. Students in the four groups reported comparable planning strategies ($b = 0.039$, $p = .394$), self-efficacy ($b = 0.055$, $p = .221$), motivation ($b = 0.023$, $p = .480$), self-monitoring ($b = 0.035$, $p = .473$), procrastination ($b = -0.039$, $p = .337$), and concentration ($b = 0.089$, $p = .102$) over the first five days of the 30-day survey period.

In a second step, we conducted multilevel regression analyses for each dependent variable and included dummy variables for the groups META (metacognitive feedback), MOT (motivational feedback), and METAMOT (metacognitive and motivational feedback) as predictors. Doing so, we tested whether average-reported SRL strategies and motivation differed for the three intervention groups compared to the control group (the reference category). Results are shown in Fig. 4. Results revealed that students in group METAMOT (metacognitive and motivational feedback) reported higher average planning strategies ($\beta = 0.09$, $p = .049$), more self-monitoring ($\beta = 0.14$, $p = .002$), less procrastination ($\beta = -0.09$, $p = .015$), and better average concentration ($\beta = 0.09$, $p = .009$) compared to the control group. Further, students in group META (metacognitive feedback) reported more self-monitoring ($\beta = 0.08$, $p = .044$) and less procrastination ($\beta = -0.10$, $p = .006$) compared to the control group. The remaining group comparisons between group META, METAMOT and CG were not significant. Further, students in group MOT (motivational feedback) did not differ from students in the control group regarding self-reported SRL strategies, nor motivation.

In sum, group comparisons of the average-reported SRL strategies revealed significant group differences, but mostly for group METAMOT. That is, the combination of metacognitive and motivational feedback improved average planning, self-monitoring, and concentration while reducing procrastination, which is in line with hypothesis H2c. However, motivation and self-efficacy reported before learning were unaffected by feedback. Hence, in contrast to our hypothesis H2b, motivational feedback did not improve students' motivation. In line with hypothesis H2a, metacognitive feedback improved self-monitoring, and reduced procrastination, but even more so if it was combined with motivational feedback.

4.3. Effects of feedback on SRL strategies and motivation from pre- to post-intervention

In a supplementary analysis, we further tested whether students in

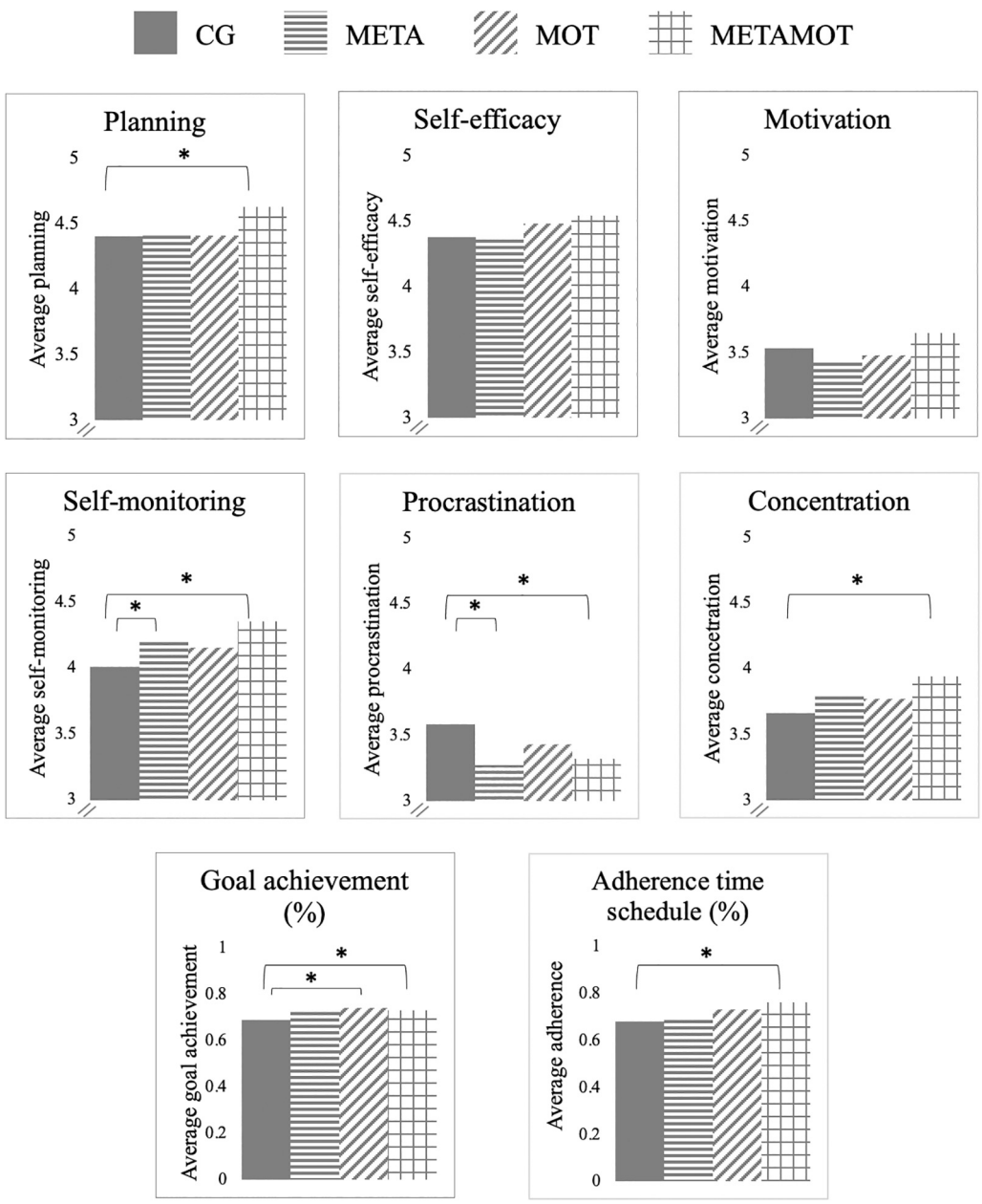

Fig. 4. Average self-regulated learning, motivaton, and achievement.
Note. The figure shows the differences in average self-regulated learning, motivation, and achievement between groups over the survey period.
* Denotes that increase is statistically significant.

the feedback groups improved their general use of SRL strategies and motivation from pretest to posttest. As this study focused on the effects of the intervention on daily reported SRL and motivation, we report the results in the supplementary analyses. In short, we found a general increase from pretest to posttest in goal setting and planning, self-efficacy, self-monitoring, and concentration. However, the feedback conditions did not improve more over time compared to the control group without feedback (see Supplementary Fig. 1). These results suggest that the feedback intervention did not improve self-reported general SRL strategies or motivation.

4.4. Effects of feedback on daily goal achievement and exam grades

Next, we tested whether receiving informative, directive, or transformative feedback improved daily learning outcomes, i.e., daily goal achievement and adherence to time schedule. Following H1, we expected that transformative feedback would enhance goal achievement and adherence to time schedule compared to receiving no feedback, or only informative feedback. Following H2, we expected that feedback (in general) would improve daily adherence to time schedule and goal achievement, but we did not specify a directed hypothesis whether the effects would differ for metacognitive or motivational feedback target. Then, we tested whether the feedback intervention improved more distal learning outcomes, i.e., exam grades. As we did not preregister this hypothesis, this analysis should be considered explorative.

4.4.1. Effects of transformative, directive, and informative feedback

Regarding the daily outcome measures, students reported higher goal achievement the day after receiving informative feedback ($b = 0.06$, $p \leq 0.001$, $\beta = 0.08$, CI [0.05, 0.12]), directive feedback ($b = 0.06$, $p \leq 0.001$, $\beta = 0.08$, CI [0.04, 0.11]), and transformative feedback ($b = 0.06$, $p \leq 0.001$, $\beta = 0.08$, CI [0.05, 0.11]) compared to when they did

not receive feedback on the previous day. That is, students reported 6% higher goal achievement after receiving any kind of feedback on the previous day compared to receiving no feedback (see Fig. 3). Moreover, students reported a higher adherence to their self-set time schedule the day after receiving informative feedback ($b = 0.07, p \leq 0.001, \beta = 0.10$, CI [0.06, 0.14]), directive feedback ($b = 0.05, p \leq 0.001, \beta = 0.07$, CI [0.03, 0.11]), and transformative feedback ($b = 0.05, p \leq 0.001, \beta = 0.07$, CI [0.03, 0.11]) compared to when they did not receive feedback on the previous day. That is, students reported a 5–7% higher adherence to time schedule after receiving any kind of feedback on the previous day (see Fig. 3). Taken together, results indicate that informative, directive, and transformative feedback improved students' daily goals achievement and adherence to time schedule.

4.4.2. Effects of metacognitive and motivational feedback target

Moreover, students in group MOT ($\beta = 0.09, p = .023$) and students in group METAMOT ($\beta = 0.07, p = .045$) reported higher average goal achievement over the 30-day survey period compared to students in group CG without feedback (see Fig. 4). Students in group METAMOT further reported a higher adherence to their time schedule over the 30-day survey period compared to students in group CG without feedback ($\beta = 0.13, p = .005$; see Fig. 4). These results indicate that especially those students who received feedback on metacognitive and motivational aspects of learning were more successful in achieving their goals and plans than students who did not receive any kind of feedback.

Then, we tested the hypothesis that students in the feedback conditions performed better in their final exams compared to students in the control condition. We found that students in the feedback groups reported better exam grades compared to students in the control group ($t(115) = 2.32, p = .022, d = 0.46$). Post-hoc contrast revealed a similar pattern when comparing the control group to each of the feedback groups, although not all comparisons were statistically significant due to lower statistical power (group META vs. CG: $t(113) = 1.54, p = .042, d = 0.49$; group MOT vs. CG: $t(113) = 1.27, p = .086, d = 0.45$; group METAMOT vs. CG: $t(113) = 1.14, p = .098, d = 0.40$). Together, these findings suggest that receiving feedback on learning diaries during exam preparation improved students' exam performance.

5. Discussion

The goal of the present study was to test the effects of daily, adaptive feedback on self-regulated learning, motivation, and achievement. Informative feedback and transformative feedback helped students to reduce procrastination and to improve planning strategies, self-monitoring, concentration, adherence to time schedules, and goal achievement compared to receiving no feedback. Directive feedback reduced procrastination and improved self-monitoring, adherence to time schedules, and goal achievement. However, as we did not have a hypothesis regarding the effects of directive feedback, these results need to be considered explorative and warrant further research. Motivation and self-efficacy were unaffected by any kind of feedback. The positive effects of the intervention were most pronounced when students received feedback on metacognitive and on motivational aspects of learning. Furthermore, students who received feedback achieved better grades in the final examinations compared to students in the control group who never received feedback. Together, these results suggest that the feedback intervention effectively improved various aspects of students self-regulated learning and achievement, but the effects varied based on feedback content.

5.1. Effects of informative, directive and transformative feedback on self-regulated learning and motivation

The effects of the feedback intervention differed depending on feedback design. We experimentally varied the informativeness of the feedback using a within-subject manipulation. Students in the feedback groups either received feed-back on their current goal progress and SRL (informative feedback), feed-forward on how to improve their SRL strategies and motivation (directive feedback), both feed-back and feed-forward (transformative feedback), or – on some days – they received neither feed-back nor feed-forward (no feedback days). Transformative feedback and informative feedback reduced procrastination and improved various aspects of students' self-regulated learning, i.e., planning strategies, self-monitoring, and concentration. Effects for planning strategies, self-monitoring, and concentration were most pronounced for informative feedback, which only included feed-back. In contrast, directive feedback, which did not include feed-back on current goal progress, failed to improve planning strategies and concentration. Hence, strategy suggestions alone may not be effective to improve self-regulated learning (Schumacher & Ifenthaler, 2021). Evidence on the effectiveness of strategy suggestions (so-called prompts) on self-regulated learning has been mixed (e.g., Prieger & Bannert, 2018). The current findings suggest that the effects of directive strategy prompts could be improved by including adaptive feed-back. Together, these results suggest that feed-back on current goal progress and potential deficits seems to be a crucial element in effective self-regulation feedback.

Our results are in line with previous studies that revealed that keeping track of one's current goal progress is an important element of effective feedback. For instance, it has been shown that feedback is more effective if it provides information about the current goal progress with respect to a specific task (Kluger & DeNisi, 1996). According to Kluger and DeNisi's (1996) feedback intervention theory, a gap between the actual and intended performance level catches learners' attention and initiates changes in behavior. In line with this, prior studies revealed that students showed more accurate metacognitive monitoring if they received repeated feedback with respect to a standard or goal (e.g., Callender et al., 2016; Nietfeld et al., 2006; van Loon & Roebers, 2017). Applied to this study, learners who know their current progress towards their goal can more easily and accurately monitor gaps between the actual and intended performance level. Accurate self-monitoring, in turn, lays the foundation for regulatory action.

Our results further extend previous studies that used learning diaries as an intervention. These studies revealed that learning diaries that included study advices or prompts improved students' SRL while simply asking students to report and reflect on their strategy use did not improve SRL (Bellhäuser et al., 2016; Broadbent et al., 2020; Dignath et al., 2015; Dörrenbächer & Perels, 2016; Loeffler et al., 2019). Our results add to these findings by showing that the group that only filled in learning diaries but never received any kind of feedback on their entries did not improve self-regulated learning. Our results thus support the idea that learning diaries alone do not automatically lead to accurate self-monitoring or self-regulation of strategy use. In contrast, receiving external feedback boosted the effectiveness of learning diaries by facilitating self-monitoring and strategy regulation.

Notably, feedback did not improve motivation nor self-efficacy. One explanation is that motivation also depends on contextual factors, such as interest in the learning topic and the design of the particular course students are studying for (Harackiewicz, Smith, & Priniski, 2016). It may also take more time than just 30 days to increase students' self-efficacy. Repeated mastery experiences build one important source of self-efficacy (Bandura, 1997). Although the feedback intervention helped students to raise their goal achievement and to improve their time management, the effects of those mastery experiences on self-efficacy may emerge with delay.

5.2. Effects of feedback on academic achievement

Feedback effectively improved students' academic achievement. Informative, directive, and transformative feedback enhanced self-reported goal achievement and adherence to time schedules compared to no feedback. Being informed about the current goal progress may

helped students to keep track of their goals and plans while short strategy suggestions additionally facilitated goal pursuit. We further explored the effects of feedback on exam performance and found that feedback improved students' grades in the final exam. As this analysis was not part of the preregistered hypotheses, this finding should be confirmed in future studies. Nonetheless, our results suggest that a parsimonious feedback intervention had a medium-sized effect on students' objective academic achievement. Besides, these results support the validity of the daily self-reports as improvements in daily self-reported SRL were accompanied by better objective examination grades. Together, our findings speak for the effectiveness of the feedback intervention to improve students' academic achievement.

5.3. Effects of feedback target

The effects of the feedback intervention differed depending on the target of the intervention. Using a between-subject manipulation, we experimentally varied whether the feedback intervention focused on metacognitive aspects, motivational aspects, or metacognitive and motivational aspects. We found that the combination of metacognitive and motivational feedback most effectively reduced procrastination and improved planning strategies, self-monitoring, concentration, goal achievement, and adherence to time schedule. These results underline that successful self-regulated learning requires effective metacognitive strategies as well as a certain degree of motivation to initiate and maintain learning processes. For instance, following process models of SRL (e.g., Zimmerman, 2000), students need to keep track of their goal progress during learning (metacognitive strategy) but they also need to avoid distractions and apply strategies to maintain their motivation (motivation regulation strategies). Hence, results support models of self-regulated learning that emphasize the interplay of various strategies including metacognitive strategies and strategies to improve motivation.

5.4. Study limitations and future directions

The current study has several limitations, which provide avenues for further research. First, self-regulated learning strategies were assessed using self-reports, which can be incorrect or incomplete due to memory biases or social desirability (Veenman, 2011). However, our daily questionnaires offer a context-sensitive, ecological valid assessment, which reduces the risk of memory biases (Panadero, Klug, & Järvelä, 2016). Nonetheless, future studies could include additional, objective data such as log-files to assess students' self-regulated learning (see e.g., Bernacki, Vosicka, Utz, & Warren, 2020; Theobald, Bellhäuser, & Imhof, 2018).

Second, we did not include a control condition that did not fill in daily learning diaries. Therefore, we cannot answer the question whether filling in learning diaries has led to reactivity effects (Panadero et al., 2016). Students might have reported better self-regulated learning and higher motivation because they were aware that they were observed by the researchers. Note, however, that reactivity effects – if they occurred – should have affected the control group and the feedback groups to a similar degree. Put differently, the positive effects of feedback (against no feedback) were observed despite potential reactivity effects. Relatedly, it has been argued that learning diaries could serve as an intervention in its own right by fostering metacognitive monitoring (Schmitz & Perels, 2011). However, prior studies showed that learning diaries alone are mostly ineffective in improving students self-regulated learning (Bellhäuser et al., 2016; Broadbent et al., 2020), and sometimes even impaired students' motivation (Dörrenbächer & Perels, 2016). Even if learning diaries helped some students in the control group to improve their learning, the daily feedback had additional effects. That is, feedback improved the effectiveness of daily learning diaries by helping students to better monitor and regulate their strategy use.

Third, we tested a heterogenous student sample. Students came from various fields of study and studied in different semesters. Therefore, the workload as well as the difficulty of the exams and learning goals may have differed. For instance, some students may have had a very strict timetable that restricted their opportunities to self-regulate their learning, which could have limited the effects of the feedback intervention. Future studies should replicate our findings in more homogenous samples, for instance, within one specific course where all students prepare for the same exam.

5.5. Practical recommendations and conclusions

Results of the present study showed that automated, individualized feedback improved daily self-regulated learning and academic achievement. We found that both, feedback on current goal progress (feed-back) as well as strategy suggestions on how to improve SRL (feed-forward) constitute important components of effective feedback (Hattie & Timperley, 2007). Hence, effective teacher feedback should include feed-back and feed-forward. Teachers should also target both metacognitive and motivational aspects of students self-regulated learning. This way, students learn that metacognitive strategies and motivation regulation strategies are crucial for successful self-regulation.

Learning diaries with automated feedback offer an important first step towards an individualized support of self-regulated learning. Future studies should extend this line of research to develop adaptive interventions that consider students' individual deficits and needs. For instance, the effectiveness of different types of feedback may also depend on the type of self-regulation deficit or on students' prior knowledge on self-regulated learning. Furthermore, on some days students may only need feedback on current goal progress. On other days, students would especially benefit from extensive strategy recommendations. Hence, future research should account for these dynamics in self-regulated learning when designing individualized interventions.

Open practices statement

Research questions, hypotheses, and methods were preregistered via the Open Science Framework (OSF) prior to conducting the study (Link to preregistration: https://osf.io/r86kb). The OSF project further contains the data used for data analysis, the data analysis script as well as an overview on questionnaire items, learning diary items, and feedback (Link to project https://osf.io/rdwc2/).

Author contributions

M.T. designed the study. Data collection was overseen by M.T. M.T. performed the data analysis and interpretation with support from H.B. M.T. drafted the paper, and H.B. provided revisions. Both authors approved the final version of the paper for submission.

Declaration of Competing Interest

The authors have no conflict of interest to declare.

Data availability

The data and the script used to analyze the data can be accessed via the Open Science Framework https://osf.io/rdwc2/.

Acknowledgments

This research was supported by a university research grant from the Johannes Gutenberg-University Mainz, Germany (Centre for Research on Schools, Education and Higher Education (ZSBH). We thank Maximilian Resch for his help in data collection.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.iheduc.2022.100872.

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