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Exploring the influence of guiding feedback on mathematical self-efficacy: Insights from a field study with engineering students

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Abstract: Feedback is considered a critical factor in supporting learners' self-efficacy. In the context of digital tasks with so-called guiding feedback, students receive error-specific hints and are offered sub-steps in case of incorrect answers. After receiving the feedback, students can immediately use it to correct their answers. Based on theoretical considerations, positive effects of guiding feedback on students' self-efficacy are assumed. Therefore, we conducted a field study involving 222 engineering students in which we offered them voluntary tasks with guiding feedback. The results indicate that students who worked on these tasks did not show significantly higher self-efficacy afterwards than students who worked less or even not at all on these tasks. However, it was found that students who used this offer had significantly higher self-efficacy in tasks with guiding feedback than in tasks for which this feedback was not provided.

Keywords: feedback, computer-based assessment, self-efficacy

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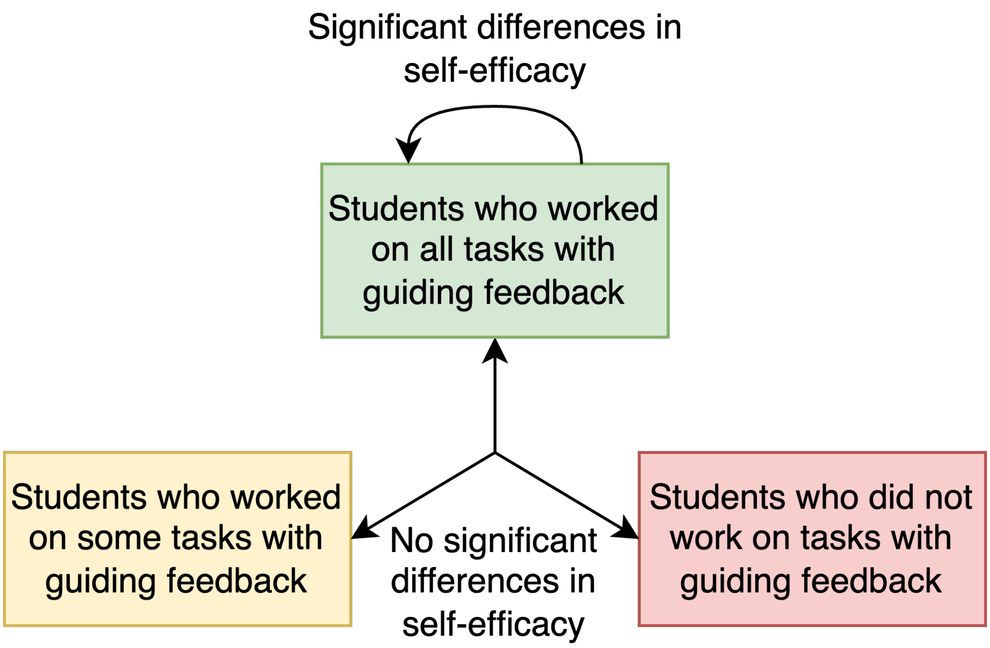

1 Introduction

Mathematical self-efficacy is considered an important factor in student learning, as it significantly determines the degree of effort and persistence in working on a mathematical problem (Hay et al., 2022). Self-efficacy can be enhanced significantly through elaborated feedback. However, elaborated feedback is not always effective because learners often do not engage with the content of the feedback in a sufficiently intensive way (Molloy & Boud, 2014). To counteract this, we have developed a feedback strategy in which learners enter task loops consisting of sub-steps in which they are supposed to apply the feedback to correct their answers. We refer to this strategy as *guiding feedback*.

The digital tasks with guiding feedback are created using STACK. With STACK, learners' answers can be analysed automatically. Moreover, students can enter loops in which they work through the entire task in several sub-steps if they answer incorrectly. The sub-steps allow the system to determine the causes of errors with greater precision, thus enabling the generation of more elaborated feedback. This is enabled by a further technical development of the system at a German university (Altieri et al., 2020). The students can immediately apply the feedback for an independent error correction.

It is assumed that guiding feedback positively influences learners' self-efficacy. To examine this assumption, a field study was conducted with 222 engineering students. This paper presents and explains the relevant theoretical background, methods and results of the study.

2 Theoretical background

2.1 Feedback

Hattie and Timperley (2007, p. 81) define feedback as responses that relate to an individual's performance or understanding. It can be distinguished between summative and formative feedback (Shute, 2008). Summative feedback, given after the completion of a task, provides information for a final performance evaluation. Formative feedback, given during the process, offers information to be used for continuous improvement of the process.

Both summative and formative feedback can be constructed using various content components. Narciss (2008) differentiates between simple and elaborated components of feedback. Simple forms of feedback are limited to providing information about the correctness of a task solution (KR-feedback) or presenting a correct result (KCR-feedback). In contrast, elaborated forms of feedback include more comprehensive information about task requirements (KTC-feedback), the solution (KH-feedback) and the location and cause of errors (KM-feedback). The elaborated components are essential for the design of an effective feedback (Kulhavy & Stock, 1989).

Effective feedback should address three key questions: "Where am I going? How am I going? And where to next?" (Hattie & Timperley, 2007, p. 88). The aim of effective feedback is to reduce the discrepancy between the current and desired state. Elaborated feedback can respond to the three questions by linking to the learner's current level of performance and providing relevant information for an independent error correction. Therefore, it can be assumed that elaborated feedback is more effective than simple feedback.

However, the effectiveness of feedback is contingent upon learners' engagement with the content of the feedback (Molloy & Boud, 2014). One approach to encourage this is offered by providing informative tutoring feedback strategies. Informative tutoring feedback strategies combine simple KR-feedback with elaborated forms such as KH- and KM-feedback (Narciss, 2012). These strategies do not directly provide the solution, but rather present elaborated feedback in the form of strategic and error-specific cues, which lead learners to actively construct knowledge. The focus is on empowering students to use the feedback to correct their answers. Consequently, learners should have the opportunity to rework tasks immediately after receiving feedback. This approach is in accordance with the Cognitive-Load Theory, as providing specific hints instead of an entire sample solution mitigates the potential for cognitive overload (Day & Cordón, 1993).

Informative tutoring feedback strategies can be created for mathematical tasks with the STACK (System for Teaching and Assessment using a Computer algebra Kernel). The computer algebra system enables the construction of digital tasks in which learners' answers are interpreted not only as character strings but also as mathematical expressions. When creating tasks, teachers can consider beforehand, for example based on literature, what possible errors learners might make. Following on from this, they can attach elaborated feedback content to specific mathematical verifications. During evaluation, the system runs through an algorithm of mathematical checks defined in advance by the teacher. If certain checks match, the associated feedback content can be presented directly to the learners (Sangwin, 2023).

The design of informative tutoring feedback strategies for digital learning tasks such as STACK tasks is a challenging issue, as the feedback must be derived from the students' final answers. Typically, the system is not aware of the calculation steps carried out by the students, which are necessary for a precise assessment of the answer and the creation of elaborated feedback. If the task were to be assessed in sub-steps from the beginning in order to gain insights into the individual calculation steps, the tasks would be simplified, and important process-related skills would not be adequately promoted. Consequently, the question remains how to deal with a situation where the cause of an incorrect answer cannot be determined.

To offer a possible approach to this, we have developed the feedback strategy guiding feedback by using the technical possibilities of STACK. In this strategy, the computer algebra system in STACK first analyses whether the entered answer is correct. If this is the case, the student receives a positive confirmation (KR-feedback). If an incorrect solution is entered, a previously programmed algorithm is executed to determine whether certain typical errors have been made. Should a potential source of error be identified, the student receives error-specific information (KM-feedback). This becomes problematic with more complex tasks where it is not sufficient to obtain only the final answer for error analysis. In the event that no cause of error can be identified, the student will be given the opportunity to enter a task loop consisting of sub-steps. These sub-steps will enable the student to gain knowledge and skills that will be required to solve the original task. As learners progress through these sub-steps, they receive error-specific hints on their answers. This enables learners to engage actively with the feedback, as they are expected to correct their errors in the task loops. Guiding feedback recommends that learners should be encouraged to use the information from the feedback in the sense of intentional error correction (Narciss, 2008). The ability to send students into a task loop after entering their answers was developed by a technical improvement of STACK, which is not yet included in the regular STACK version (Altieri et al., 2020).

2.2 Self-efficacy

Self-efficacy is a fundamental construct in the research of learning processes and can be significantly influenced by feedback. Bandura (2012) defines self-efficacy as an individual's conviction of being able to perform a certain action successfully in a specific situation. The strength of self-efficacy has a major impact on one's performance. Difficult tasks are classified as achievable challenges rather than barriers when self-efficacy is high. Consequently, individuals with higher self-efficacy set themselves more challenging goals and are willing to invest more time and effort in achieving them. As part of his social cognitive learning theory, Bandura (2012) assumes four different sources that can influence an individual's self-efficacy. These are composed mastery experiences, vicarious experiences, physiological state, and feedback.

For example, Wang and Wu (2008) investigated the effect of different forms of feedback on students' self-efficacy. 76 students from 23 different teacher training courses were assigned tasks related to their respective course and then different forms of feedback. They were then provided with different forms of feedback on their solutions. The results of the study indicate that students who received elaborated feedback exhibited significantly higher self-efficacy than those who received simple feedback.

This empirical finding can be explained by the cognitive and motivational functions of elaborated feedback. Elaborated feedback has been shown to have a significant impact on achievement (Hattie, 2023). Higher achievement is associated with greater experiences of success, which promote self-efficacy (Bandura, 2012). Motivational functions consist of revealing prior learning achievements and attributing them to favourable attributions. Elaborated feedback can help in convincing learners of their own abilities by revealing aspects of the solution that are already correct. To achieve the correct solution, learners must engage intensively with the content of the feedback. By doing so, they contribute more in correcting their solutions and increase their confidence in being able to master the tasks (Narciss, 2008).

3 Methods

3.1 Research questions

After clarifying that elaborated feedback can have a positive effect on self-efficacy, the question arises to what extent guiding feedback could contribute to the promotion of mathematical self-efficacy. There are already several articles that theoretically describe the design possibilities of informative tutoring feedback (e.g. Narciss & Huth, 2004) and its potential motivational effects (e.g. Narciss, 2017; Narciss & Zumbach, 2023). However, there are hardly any studies that empirically investigate motivational effects of a developed informative tutoring feedback strategy, such as guiding feedback, in mathematics education. This research is essential for a broader use of these strategies in mathematics teaching. Hence, this study aims to minimise the research gap by investigating the following two research questions:

1. How does students' self-efficacy differ depending on the number of performed preparing tasks with guiding feedback?
2. How does the self-efficacy of students who complete all the preparing tasks differ between primary tasks for which preparing tasks with guiding feedback do and do not exist?

While the first research question compares the self-efficacy of different students, the second research question compares the self-efficacy of the same students in different situations. Consequently, the first group comparison is a between-subjects design and the second is a within-subjects design. Based on the assumed positive effects of guiding feedback on self-efficacy, the following two hypotheses are suggested:

1. A higher number of performed preparing tasks with guiding feedback will lead to higher self-efficacy.
2. Students who completed all preparing tasks with guiding feedback achieve higher self-efficacy on primary tasks for which preparing tasks do exist than on those for which preparing tasks do not exist.

3.2 Sample, procedure and materials

The study involved 222 engineering students who had attended a mathematics course at a German university. Participation in the study was voluntary. In the mathematics course, students were given ten tasks to work on during the semester. These tasks could only be worked on once. After the submission deadline, students received sample solutions and were credited with additional points for the exam. These tasks are referred to as primary tasks.

For five of these ten primary tasks, preparing tasks with guiding feedback were provided. The preparing tasks required the same competencies and had a similar level of difficulty as the primary tasks. Nevertheless, they differed by their numerical values and content contexts. The students were free to work on the preparing tasks before starting the primary tasks. The preparing tasks could be worked on and submitted multiple times. This allowed students to decide for themselves how many similar preparing tasks they would like to work on before moving on to the primary tasks. All tasks were related to probability and statistics.

Students' self-efficacy was assessed by asking them before working on each primary task to indicate on an eight-point Likert scale to what extent they were confident in their ability to work on the respective task (from "I do not trust myself at all" to "I trust myself completely"). This approach is in line with Bandura's (2006) recommendations and has been implemented in several studies (e.g. Pajares, 2004).

In classifying the ten primary tasks into five with preparing tasks and five without, it was considered that both types of tasks are distributed over the time of the semester. Furthermore, it was ensured that both task types had the same level of difficulty and that the tasks with preparing tasks were not easier than the ones without. This was checked afterward based on the achievement of students who did not work on the preparing tasks (n = 80). These students achieved an average of 15% of the possible points for the primary tasks for which there were preparing tasks and an average of 18% for the tasks for which there were no preparing tasks. This result indicates that the primary tasks for which preparing tasks were available were approximately as difficult as the primary tasks for which no preparing tasks were available.

4 Results

Table 1 presents the results for the first research question. The table contains data on students' self-efficacy in primary tasks for which preparing tasks existed. The three groups presented in the table (0, 1, and 2) represent students who completed different numbers of these preparing tasks. Group 0 (n = 22) comprised students who had not completed any preparing tasks. Group 1 (n = 105) consisted of students who had completed between one and four preparing tasks. Group 2 (n = 95) comprised students who had completed all preparing tasks.

Table 1. Analysis of variance for average self-efficacy in primary tasks for which preparing tasks existed.

Group	*N*	*M*	*SD*	*H*(2)	*p*
0	22	4.72	1.59		
1	105	5.02	1.73	1.38	.500
2	95	5.11	1.88		

A parameter-free statistical test (Kruskal-Wallis test) was calculated since the distributions of the mean values are not sufficiently normally distributed in all groups. The average differences between the groups are not statistically significant. Based on the analysis of variance, the first hypothesis that a higher number of completed preparing tasks with guiding feedback leads to higher self-efficacy cannot be confirmed.

In Table 2, results answering the second research question are presented. The data presented in Table 2 pertains solely to students in Group 2. In other words, only students who have completed all preparing tasks are included. The self-efficacy of these students has been compared in the context of primary tasks for which preparing tasks do and do not exist are compared.

Table 2. Wilcoxon test for average self-efficacy in primary tasks for which preparing tasks do and do not exist.

Task type	*N*	*M*	*SD*	*z*	*p*	*r*
Primary tasks for which preparing tasks do exist	95	5.11	1.88	-2.02	< .001	.65
Primary tasks for which preparing tasks do not exist	95	4.37	1.88			

A Wilcoxon test was calculated because the distribution of mean differences is not sufficiently normally distributed ($W = 0.92$, $p < .001$). The differences in the average self-efficacy between the two task types were found to be statistically significant. This result supports the second hypothesis that students who completed all preparing tasks with guiding feedback achieve higher self-efficacy on primary tasks for which preparing tasks do exist than on those for which preparing tasks do not exist. The effect size of $r = .65$ can be interpreted as strong (Cohen, 1992, p. 157).

5 Discussion

The first hypothesis, that a higher number of completed preparing tasks with guiding feedback leads to higher self-efficacy, could not be confirmed based on the analysis of variance. One possible reason for this is that the sample size of group 0 is too small. The majority of students who did not complete the preparing tasks largely did not report their self-efficacy, which makes the data of this group not sufficiently representative. Another potential explanation for this discrepancy could be that students who did not complete preparing tasks differ from the other students in terms of other characteristics. Consequently, the observed differences in self-efficacy cannot be attributed solely to the processing of the preparing tasks.

It is possible that students who did not complete the preparing tasks may have overestimated their achievement more than students who did complete the preparing tasks. One potential explanation for this discrepancy is that students who did not complete any preparing tasks may have incorrectly assumed that they could solve the tasks due to the lack of error-specific feedback (Talsma et al., 2019). This assumption is likely to be associated with the observed low achievement of this group of students. However, further detailed analyses are required to confirm this assumption with sufficient certainty.

In order to gain a more profound comprehension of the impact of the preparing tasks, it is essential to contemplate the outcomes of the second research question. Students who have completed all of the preparing tasks have been observed to exhibit significantly elevated self-efficacy on tasks with preparing tasks in comparison to those without. This group comparison is no longer a between-subjects design, but a within-subjects design. In this comparison, the same students are within the two groups, which consequently enhances the statistical power of the test due to the lower error variance. The significant results of the Wilcoxon test reinforce the assumption that students differ too much in other factors in the analysis of variance, making it difficult to discern the effects of the preparing tasks.

The large effect size in the linked sample test ($r = .65$) can be attributed, among other things, to the characteristics of the preparing tasks. The guiding structure of the feedback in these tasks most likely led to a more accurate diagnosis of error causes. The combination of elaborated feedback content and sub-steps enabled students to immediately apply the feedback content to correct their inputs. The elaborated feedback probably led to a more intensive engagement with the task and could thus unfold its effects, so that the students exhibited a higher self-efficacy in the tasks for which preparing tasks existed than in those for which none existed (Molloy & Boud, 2014). Moreover, correct calculations were positively highlighted within the feedback, so the preparing tasks could influence learners' self-efficacy not only through their cognitive but also through their motivational functions (Narciss, 2008).

Nevertheless, it should be noted that the general processing of the preparing tasks could also have contributed to the promotion of self-efficacy independently of the feedback. The strength of the pure effect of the guiding feedback is unclear. To address this question, a further experimental study is required in which an additional group is included that only works on preparing tasks and receives no feedback or another form of feedback. In such a comparison, a significant effect on self-efficacy could no longer be attributed to the mere completion of the tasks. However, this study is to be regarded as a field study and was not aimed at an experimental comparison of controlled groups.

6 Conclusions

The study examined the effects of guiding feedback on students' self-efficacy. Although a higher number of completed preparing tasks with guiding feedback did not lead to higher self-efficacy, it was found that students who completed all preparing tasks had higher self-efficacy on tasks with preparing tasks than on those without. The high effect size confirms the positive effects of the guiding feedback that were suspected in advance.

Even if the promotion of self-efficacy is desirable, it should be noted that a misjudgement of one's abilities is associated with negative consequences. Therefore, it remains to be investigated whether guiding feedback leads to a higher achievement overall and thus is not accompanied by a strong overestimation of one's competencies.

Furthermore, additional experimental studies are required to compare guiding feedback with other feedback strategies in a controlled setting. This will enable more precise conclusions to be drawn about the effect of this feedback strategy.

Research ethics

Informed consent was obtained from all research participants. The author declares no conflicts of interest.

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