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This study reports on findings from an empirical investigation into the use of three different forms of feedback in digital material for learning mathematics: correctness feedback, attention feedback, and explanation feedback. All feedback types are received immediately by the students. In total 267 upper secondary school students used the material during a lesson and data from the system, a questionnaire and observations were collected and analysed. The results show that correctness feedback drives the learners' engagement, while explanation feedback helps learners to build understanding but is often skipped by learners as it is time-consuming. This study suggests that attention feedback, in which the essentials or critical aspects are highlighted without giving all details, is often sufficient in this setting and retains learner autonomy.

Keywords: Mathematics learning, feedback, immediate feedback, digital learning material,

Introduction

At the Akelius Math Learning Lab[1], digital learning materials are being developed to teach mathematics, specifically targeting 7 to 18-year-olds in refugee camps and under-resourced schools in the Global South. The material will be made accessible offline on simple tablets in multiple languages. The digital environment offers educational opportunities to learners with limited access to teaching, ensuring the availability of course materials and feedback. The learners move at their own pace and revisit lectures if they want.

Feedback is considered an important and effective aspect of learning (Black & Wiliam, 1998; Hattie & Timperley, 2007; Shute, 2008; Wiliam, 2016). When creating a digital system for giving feedback there is a need to understand how learners use and benefit from different types of feedback. This study seeks to explore the impact of different feedback forms on learners using digital learning material for learning mathematics. Specifically, we examine learners' interactions with and reactions to the feedback. The research aims to answer the following research question: How do learners react to three feedback forms correctness feedback, attention feedback, and explanation feedback, in a digital learning environment for learning mathematics?

Theoretical framework

To frame our analysis, we begin by examining the concept of feedback. According to Hattie and Timperley (2007), feedback can be defined as "information provided by an agent (e.g., teacher, peer, book, parent, self, experience) regarding aspects of one's performance or understanding" (p. 81).

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[1] https://www.akelius-math.com/en/about

Meta-analyses show that feedback significantly influences learning (Hattie & Clarke, 2018), but its effect can vary, it can both help and slow down progress, depending on the situation, form, and content of the feedback. It is therefore important to conduct a fine-grained analysis to develop productive feedback adapted to the specific learning situation. In particular, feedback in a digital setting must be tuned in advance, for use in the absence of a teacher.

Effective feedback, as outlined in Hattie´s model, should address three critical questions: "Where am I going?" (the goal), "How am I going?" (current progress), and "Where to next?" (steps to improve). For feedback to be instructional, it needs to offer specific information about the task or learning process, helping to bridge the gap between the learner’s current understanding and the desired level of mastery (Sadler, 1989).

The literature differentiates between different forms of feedback (Barana et al., 2021), particularly between elaborate feedback, which provides detailed guidance, and corrective feedback, which merely indicates correctness. Studies suggest that elaborate feedback, such as explanations, reading links, and worked examples, is more effective in enhancing learning.

Barana et al. (2021) conducted a study on student performance in a digital learning environment for mathematics. They analyse results for three types of tasks, with associated forms of feedback: simple tasks with *corrective feedback*, i.e. information on whether the answer was right or wrong, more complex tasks with *interactive feedback*, which provides step-by-step guidance to students who have reached a wrong answer (or have answered right but chosen to verify their answer), and *guided activities*, which lead the student in an interactive exploration process, without building on a previously asked question. Their finding, derived from analysing platform data, show that the tasks with interactive feedback result in frequent improvement when students reattempt tasks they initially failed, whereas corrective feedback only, or guided activities, yielded minimal improvement. The framework developed by Barana et al. (2021) provides a starting point for how we classify different forms of feedback. Similarly to the authors we use corrective and interactive feedback.

Baker et al. (2010) studied, among other things, the impact of boredom, frustration, confusion, engaged concentration, delight, and surprise on students’ results in different learning environments. Interestingly, emotions such as frustration seem to have little to no effect on learning outcomes. The authors even suggest that “frustration may not need remediation” (p. 227). This is echoed in the work by Mentis (2007) who suggests that frustration only requires intervention when it stems from factors unrelated to cognitive learning efforts.

Shute (2008) discusses the impact of formative feedback on learning, including how timing affects students' emotions. While the article covers various subjects, mathematics examples are prominently featured, showing how immediate feedback can mitigate negative emotions and enhance learning. Hannula’s (2012) study delves into how emotions like frustration and enjoyment influence students' attitudes and behaviours in mathematics learning, highlighting the significant impact of these emotions on student engagement. Fyfe & Rittle-Johnson (2016) specifically examine how the timing of feedback in mathematics tasks affects learning and retention, with a focus on how immediate feedback can help manage frustration and improve problem-solving skills.

The implementation of feedback in the digital learning material

Active learning is one of the pedagogical foundations for the digital learning material used in this study. This approach emphasises that learners should engage in activities beyond listening and reading. They should actively express their thoughts and reasoning (Freeman et al., 2014). Active learning is widely recognised and empirically supported within educational research as a powerful approach to improving learning outcomes (Freeman et al., 2014). This has been implemented in this learning material by abstaining from instruction videos or texts and instead prompting learners to answer questions continuously throughout their learning process. The questions come in various formats such as multiple-choice, sorting objects, connecting objects or asking for a numerical value. Notably, there are no free text questions or questions where the full calculations are asked for. The design aims to guide learners incrementally to facilitate understanding of mathematics through engagement and immediate and varied feedback mechanisms.

The most frequent form of feedback is *correctness feedback*. This is done by showing the learner their answer alongside the correct one. Correctness feedback is given after each question. It does not include intermediate steps or guidance on how to arrive at the correct answer.

At the other end of the feedback spectrum, we have *explanation feedback*. If the learner submits an incorrect answer, they can receive an elaborate and full explanation. This is done in alignment with the principles of active learning. The learners are guided through small intermediate steps by answering questions which guide them through all the steps required for answering the original question. Once the learner completes these steps, they are given the opportunity to attempt the original question again before moving forward. For questions where explanation feedback is available, it is optional for learners who has answered correctly but may not be skipped by those gave a wrong answer.

The objective of explanation feedback is to ensure that learners actively engage with all steps in the solution, find where their thinking was faulty, reflect on their errors, reinforce correct steps and support the consolidation of the whole process. Explanation feedback is similar to what Barana et al. (2021) call interactive feedback. However, since interaction is the core of the digital material we choose to use another name for this form of feedback.

Finally, we have the feedback form *attention feedback*. This is a form of feedback that intends to give the learner some idea on how to find the right answer without giving a full detailed explanation. Instead, attention feedback intends to shift the learner’s attention to some critical aspects. In this material, this is done by asking thought-provoking- or leading questions or by directing the learner’s attention to key features in an image by circling or using arrows. Sometimes only audio is used to highlight some key aspects. The attention feedback does not require the learner to do anything. The learner can disregard it and move on directly. Attention feedback includes correctness feedback, as seen in Figure 1.

For questions where attention feedback is available, it is given to all learners, also to those who answered correctly. The idea is that this form of feedback can ensure those who answered correctly that their thinking, not only the answer, was correct. The learner is free to move on at any time.

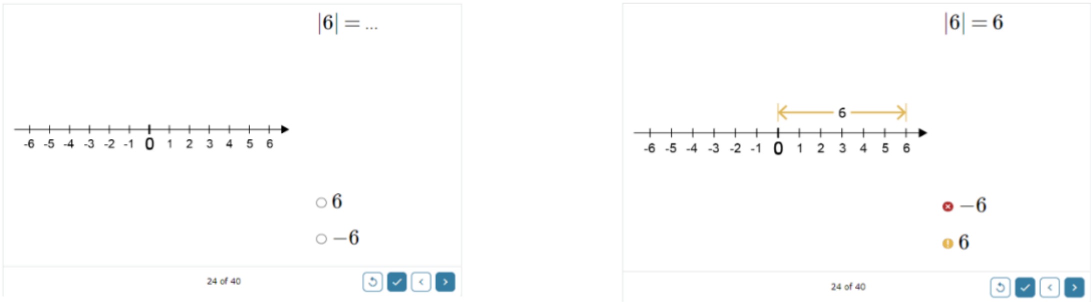

Figure 1: An example of attention feedback. To the left the question is given and to the right the feedback given. A yellow arrow draws the learner's attention to the distance to the origin.

Method

The study's empirical approach involved using the learning material in a classroom setting, allowing for an analysis of how students interacted with the material and responded to the various feedback types. Data was collected in ten classes of 17- to 18-year-old students in upper secondary school in Sweden, during the spring of 2024, with 267 students in total. This was a convenience sample where the respondents were of the right age and appropriate pre-existing knowledge, but from a more homogenous background compared with the intended target group.

Some of the students study mathematics-intensive programs. They worked with lessons about the absolute value, a concept they would normally learn about a few weeks later. Other students studied in programs with less exposure to mathematics. They worked with lessons on systems of two linear equations with two unknowns, something they had not met quite yet. Hence, neither of the groups had been taught the chosen topic in class beforehand. Both groups had in total around 40 minutes to complete as many tasks as possible from the 60 tasks available.

Three types of data were collected. System data consisting of learners' results and time spent on tasks in the learning material, a questionnaire about their experiences with the material, and finally observations in class. The total amount of respondents in the learning material and questionnaire was 246 and 267 respectively.

The questionnaire consisted of 18 questions. In the first section, the respondent consented to being part of this study and entered anonymous code making it possible for the researchers to connect the responses in the digital learning material to the answers to the questionnaire. The second section was on the overall experiences of the material. In the last part of the questionnaire, the focus turned to experiences of separate tasks. Responses to free text questions related to two of the multiple-choice questions are analysed in this report. These two questions are the following (the relevant multiple-choice options will be given in the result section):

Question 17: Sometimes, when you gave an incorrect answer, you entered a sequence with step-by-step explanations on how one can think. What do you think about that?

Question 18: Sometimes you got the option to get an explanation when you had given the correct answer. What do you think about that?

In each class, the observations were made in two different settings: in full classroom settings, where the learners worked individually, and in pair settings, where the learners worked in pairs. In the classroom setting, there were approximately 25 students who worked individually with the learning material on laptops and earphones connected for sound. The observers, consisting of both the authors of this paper and other staff at Akelius Math Learning Lab, walked around and made notes on a protocol focusing on three main themes: how the system was experienced, how the mathematics was perceived and what emotions and reactions were evoked. The protocol was developed by the observers. While preparing for data collection the observers discussed what themes to focus on to ensure reliable and uniform data collection. The classroom setting was used to get many individual reactions from learners using the system in a way that the system most often will be used.

In the pair setting, two students worked in front of a laptop. They were encouraged to collaborate and talk out load about their thinking. This setting was used to get better insight into the respondents' experience by listening to the learners. These groups of students only left the trace of one user on the learning system, while answering the questionnaire individually. This explains why there are more respondents in the learning material than in the questionnaire.

To avoid issues of privacy and integrity, each student was randomly given an anonymous code only indicating which class the student attended. No names or other personal data about the students were collected. The anonymous code was only used to connect the students' results in the learning material with their responses to the questionnaire. Students that worked in pairs both used the same anonymous code when answering the questionnaire.

We used qualitative content analysis to analyse the data from the observations and the written comments given in the questionnaire (Krippendorff, 2018). Two authors participated in coding the data. The procedure for coding started with identifying all questionnaire comments and observations that were related to feedback. These were then categorized into one of the three forms of feedback.

The researchers then searched for recurring themes within each feedback category. This was done inductively. At the end of each phase of analysis, the entire research group validated the categories that emerged from the content analysis. The validation process involved comparisons of the researchers' categorisations, and in cases of disagreement, the categorisation was discussed until a consensus was reached.

Some results

The proportion of correct answers overall was 84 %. Hence, the level of difficulty was such that most students did okay without direct instructions. Nonetheless, some students expressed a desire for more direct instruction and less reliance on feedback.

> Learner Vin44: Some tasks were like "here you get a task, try to solve it" as I said, I think it's better if someone explains how to do it before I make a mistake and not after.

Many learners reacted strongly when they received *correctness feedback*. They were keen on getting everything right and generally reacted with discomfort when they were incorrect.

> Observer NF: "Facepalm" when he gave an incorrect answer. I got the feeling that he thought it was a careless mistake. He was concerned about getting it right.

The correctness feedback in this learning material do not only show if the answer is correct or not, but also gives the correct answer. Therefore, the material typically does not allow learners to redo the questions they failed, which quite a few respondents wanted.

> Learner Box77: That you could redo the questions you did wrong (What can be improved?)

On the other hand, the observations showed that learners did not always bother to check what the right answer was.

> Observer KT: Clicks past without checking what he did wrong on several pages.

Explanation feedback was only given sparsely in the material. Learners requested more opportunities to receive this type of feedback.

> Learner Tid11: Ask after each answer if you [the learner] want an explanation of what you did wrong.

For those who received the explanation feedback, it often helped them understand the material better. Out of 267 respondents to question 18 in the questionnaire 110 selected the option "The explanation feedback helped me understand". This was also seen in the observations.

> Observer NF: "Now I understand!" Understood after the explanation feedback.

However, the explanation feedback is time-consuming. For example, at one of the questions that offered explanation feedback, 39 out of 149 learners answered incorrectly. The explanation feedback given consists of five extra questions guiding their thinking before they could answer the original question again. These learners spent in mean spent 80 seconds on this explanation feedback, including redoing the original question.

Some of these would have liked to have continued without explanation feedback.

> Observer AH: They make mistakes but immediately understand why, are still "forced" into the explanation feedback.

Among the remaining 110 learners, who answered correctly to the same question, 11 chose to get the explanation feedback. This is mirrored in the questionnaire where 142 out of 267 respondents to question 18 chose the option "I always choose to skip the explanation feedback". This was the most common respons to this question.

The third form of feedback, *attention feedback*, gives more information than correctness feedback but is less instructive and time-consuming than explanation feedback. Students normally spend just a few seconds looking at the attention feedback and are free to continue at any time.

The data indicated that this was sufficient for many learners.

Observer NF: [The learner …] Continued with only correct answers after looking at the attention feedback on page 8.

For other students, attention feedback was not enough.

Observer SB: They had difficulty understanding the attention feedback given through audio concerning the absolute value of -5.

That the learners could skip the attention feedback had consequences. There were many observations of learners who failed the question but still did not spend much time on the attention feedback. However, data shows that learners that answered incorrectly spent more time, in most cases double the time or more, on the attention feedback.

Discussion

Common types of feedback in a conventional classroom setting are notifying the student if the answer is right or wrong and giving the learner access to the correct answer. In this study we examined the former feedback type, labelled correctness feedback. The results from this study indicate that students view the use of correctness feedback as beneficial and/or helpful.

Explanation feedback is given to students who have responded incorrectly on certain questions. Students' general opinion on this feedback type was quite divided. Some expressed frustration that they were forced into a long loop while others wanted this type of feedback more often. However, the most frequent response was that this feedback type helped students' understanding. Although some students were frustrated that they were forced by the system to stay on this feedback type, it might have been to their benefit. In contrast, students were able to skip the attention feedback type, and this appeared to be a common occurrence, even to the detriment of their own understanding. One student mentioned that they skipped a lot of these feedback types and then realized that they lacked vital information to solve the upcoming questions.

Attention feedback was given to all students, with no regard to whether their answer was correct or not. Students were provided key insights regarding the studied topic. Some students considered this feedback type to be insufficient, asking for explanation feedback instead. Others thought that they could use this information before they answered the question – making the information more like a hint than actual feedback. This can perhaps be attributed to how they have been taught mathematics previously. However, an interesting follow-up on this topic would be to compare how students fared when getting the same information before and after responding to a question. Additionally, students commonly chose to skip this feedback type.

A future iteration should, in the case of an incorrect response, include the possibility of a new chance on the same question after receiving attention feedback. This might encourage students to absorb the information in the attention feedback, knowing they can make use of it.

Student reactions, as observed by the researchers and in the questionnaire responses, suggest that adding a possibility to return to a question that they answered wrong, and correct their answer. could help dissipate the frustration caused by negative feedback. It would be interesting to test a set-up where students get the possibility to answer a new, similar question to correct themselves in case they have answered wrong. A risk with such a set-up is that some students may not make the effort to try to answer right on their first try, knowing that they will get correctness feedback and a new chance.

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