Erroneous Examples: A Preliminary Investigation into Learning Benefits ⋆

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Abstract. In this work, we investigate the effect of presenting students with common errors of *other* students and explore whether such erroneous examples can help students learn without the embarrassment and demotivation of working with one's own errors. The erroneous examples are presented to students by a technology enhanced learning (TEL) system. We discuss the theoretical background of learning with erroneous examples, describe our TEL setting, and discuss initial, small-scale studies we conducted to explore learning with erroneous examples.

1 Theoretical and Empirical Background

Correctly worked examples have traditionally been used to help students learn mathematics and science problem solving and have proven to be quite effective (1; 2). However, *erroneous examples*, that is, worked solutions including one or more errors that the student is asked to detect, explain, and/or correct, have rarely been investigated or used as a teaching strategy, particularly not in technology-enhanced learning systems. The question of if – and how – erroneous examples are beneficial to learning is still very much open.

Some theoretical and empirical research has explored the effects of erroneous examples in mathematics learning and provides some evidence that studying errors can support learning by providing new problem solving opportunities and motivating reflection and inquiry, e.g. (3; 4; 5). Moreover, the highly-publicised TIMSS studies (6) showed that math students in Asian countries – where curricula often include the careful analysis and discussion of incorrect solutions – outperform their counterparts in most of the western world. One study explored self-explaining correct and incorrect examples (7; 8). Siegler et al found that when students self-explained *both* correct and incorrect examples they learned more in comparison to self-explaining correct examples only. Grosse and Renkl

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also showed some learning benefit of erroneous examples but only for learners with strong prior knowledge and for far transfer learning (9).

We plan to take the earlier studies further by investigating erroneous examples used in the context of TEL. In contrast to other studies, we are interested in the correlations between students' benefit from erroneous examples and the situational and learner characteristics, with an eye toward eventually *adapting* erroneous examples instruction. To this end, we use the adaptive learning platform ActiveMath (10), a web-based learning environment for mathematics. In contrast to the Grosse and Renkl work, we are investigating erroneous examples *with* help. Our primary rationale for including help in the empirical studies is that students are not accustomed to working with and learning from erroneous examples and, hence, they need assistance and support in doing so.

We hypothesise that learning from the 'errors of others' can help students enhance their cognitive competencies as well as their meta-cognition and learning orientation. We propose two primary reasons for this. First, a student can best learn error detection and correction by reviewing and studying errors, something that is impossible to do with correct examples – and difficult to do with unsupported problem solving. Second, reviewing erroneous examples appears to be more supportive of a learning orientation rather than a performance orientation.

Furthermore, we hypothesise that students will benefit from erroneous examples when encountered at the right time and in the right way. Rewarding a student for error detection may lead to marking of errors in memory such that they will be avoided in subsequent retrieval. Moreover, a student is less likely to exhibit the feared 'conditioned response' of behaviourism (i.e., internalising the error and repeating it) when studying the errors of other students, since the student has not made the error him/herself and thus has not necessarily internalised it. A student is also unlikely to be demotivated by studying someone else's error(s), as may be the case when emphasising errors the student has made him or herself. On the contrary, in an earlier observational study, we noticed positive motivational effects of erroneous examples (11).

Another issue that we plan to investigate in our research is what system affordances are prerequisite to integrating the benefits of erroneous examples in a learning system and, more specifically, what extensions are necessary to the existing ActiveMath system to implement such affordances.

2 Erroneous Examples in ActiveMath

Observational Study To begin investigating our research questions on erroneous examples, we designed and conducted an observational study with 25 German 6-graders. The study included two phases, error detection and error correction. Figure 1 displays both phases of an erroneous example presented to a student. The translation (of the first phase) is: *Susanne mixes* 3 *l of milk and* $\frac{4}{6}$ *l syrup. Susanne calculates how much milk shake is made by adding* 3 *and* $\frac{4}{6}$*. Her result is a* 2 *l milk shake. Find the error in Susanne's calculation. Click on the first erroneous step.* The student is asked to spot the erroneous step (Schritt 1 in

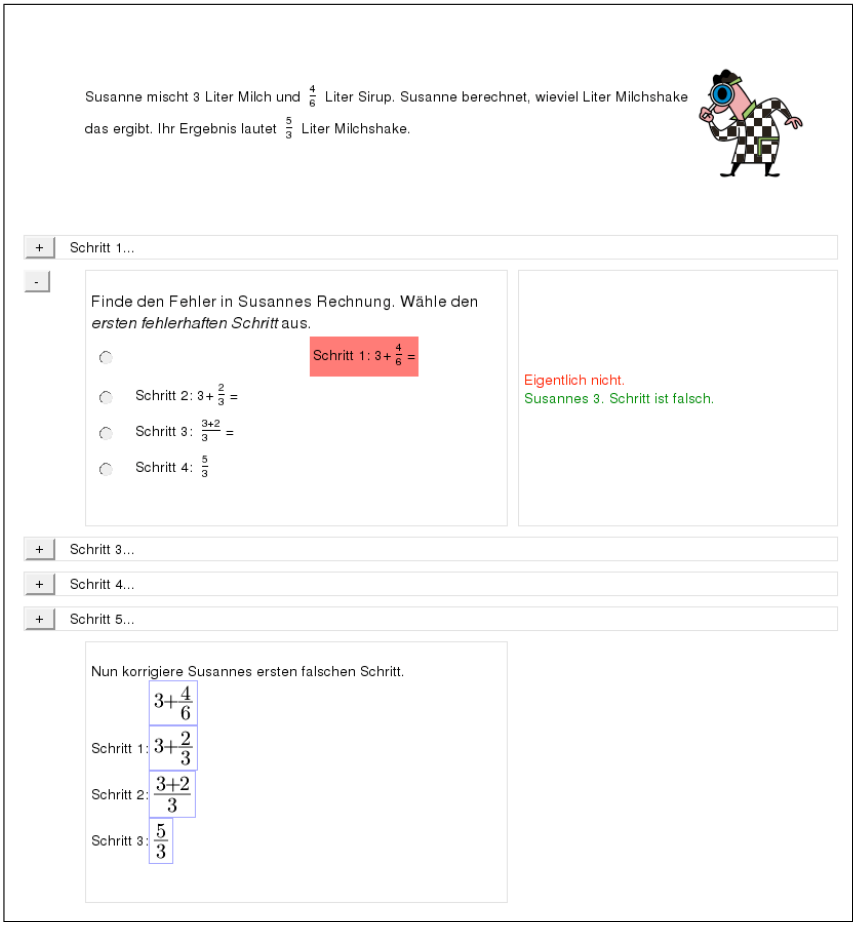

Fig. 1. An erroneous example

Figure 1) and then to correct it (Schritt 5 in Figure 1); feedback varies between conditions. For instance, in Figure 1 the student selects a correct step as incorrect (i.e., Step 1) and is flagged. The feedback (translated) is "Not really. Susanne's 3rd step is wrong". After displaying the help message, the system asks the student to explain the error, in Figure 2, "Why is the 3rd step wrong?" with the choices

- because Susanne must translate the integer 3 into a fraction
- because 3 has to be added to both the numerator and denominator of $\frac{2}{3}$
- because the 3 has to be cancelled: $\cancel{3}+\frac{2}{\cancel{3}}$
- I don't know.

The first selection is the correct choice. After completing this phase, the student is prompted to correct the error, as shown at the bottom of Figure 1 (Schrit 5, "Now, correct Susanne's first wrong step").

Observations A key observation was that the 6th grade students frequently did not know how to correct the erroneous step, even when they were able to choose the correct explanation for the error. This may mean that although students know the correct rules for performing operations on fractions and can recognise explanations that refer to these rules, they still have knowledge gaps that surface when asked to correct the error. Ohlsson (12) has described this phenomenon as a dissociation between declarative and practical knowledge. The same phenomenon occurred even with students who could solve exercises, but could not correct the erroneous example of the same type, e.g., addition of fractions with unlike denominators. Our interpretation in this case is that students tend to solve problems following well-practiced solution steps, so their knowledge gaps are not always revealed when solving exercises. We believe these gaps may be detected through the use of erroneous examples.

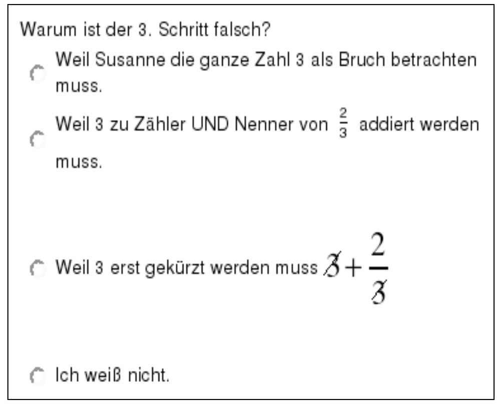

Fig. 2. Choices for Explaining the Error

Feedback Design Based on this observation, we designed feedback for helping students correct the error. There are three types of unsolicited feedback provided: minimal feedback, error-awareness and detection (EAD) feedback, and help. Minimal feedback, consists of flag feedback (green colouring for correct and red for wrong answers) along with a *correct/incorrect* indication. EAD feedback intends to support the meta-cognitive skills of error detection and awareness. For example, for the task in Figure 1, the English EAD feedback would be *"Susanne's result cannot be correct because* $\frac{5}{3}$ *l is even less than the 3 l milk"*. In the first phase of the erroneous examples (finding the error), students get EAD feedback, and then multiple choice questions (MCQs) which scaffold them to correcting the error. MCQs are explanations of the error like the ones in figure 2 and are nested (3 to 4 layers). Finally, they get minimal feedback and help messages on their choices, and eventually the correct answer. In the correction phase, error correction feedback is provided, e.g., *You forgot to expand the numerators.*

Technical Experiment Support To facilitate TEL studies with erroneous examples, we implemented an automated presentation of the study materials for use in a classroom setting. All materials are selected through a specific strategy of ActiveMath's exercise sequencer, which defines the order in which students from a condition/group receive their material. On top of this, a selection routine was implemented that randomly chooses the order in which the sequences of the intervention appear each time a new user logs onto the system, and starts off where it stopped after a break (necessary for longer TEL experiments). Moreover, all materials are online, including pre- and post-questionnaires. These features are important for running controlled studies in classrooms in general. Additionally, the erroneous examples and feedback described above, as well as the GUI that represents the worked examples, exercises, and erroneous examples are implemented as a tutorial strategy in ActiveMath.

Pilot Study Later, we ran a study informed by the initial observational study, to get preliminary indications of learning effects, to test the erroneous example design, and the online presentation of examples by ActiveMath. Ten 8th-graders were randomly assigned to one of two conditions (five per condition), and completed the pilot study in two sessions. The condition No-Erroneous-Examples (NOEE) included worked examples and fraction exercises, but no erroneous examples. The condition Erroneous-Examples-With-Help (EEWH) included worked examples, exercises, and erroneous examples with provision of help. The design followed a pretest-familiarisation-intervention-posttest schema, with questionnaires also provided. Each group solved five sequences of three items. The posttest consisted of five exercises and two erroneous examples, including conceptual questions on error detection.

Although our sample size was too small for inferential statistics, our descriptive statistics showed that the performance of the NOEE group decreased in the post-test (pre-/post-test difference mean=-13.7, stdv=13.6), whereas the EEWH group's performance, increased (pre-/post-test difference mean=13.1, stdv=7.7). The EEWH condition reported in a group interview that they were satisfied with the help provided by the system and found it easy to understand. No difference in performance was observed in how the students from the different conditions answered the conceptual questions and solved the erroneous examples. However, with scores of 60% vs. 55%, there was certainly room for improvement in conceptual understanding. A positive outcome of the study was that all students reported that it was enjoyable to work with the system (e.g. "It was fun until the end!") despite complaints that the system was not fast enough (due to server problems).

3 Outlook

In upcoming studies we plan to investigate the interplay between the two competencies: finding and explaining an error vs. correcting it. In particular, we would like to test if we can eliminate the observed discrepancy that less-advanced (6th-grade) students could find and explain errors, yet could not correct them. Ohlsson (12) argues that when the competency for finding errors is active, it functions as a self-correction mechanism that, given enough learning opportunities, can lead to a reduction of performance errors. Although reducing ones own errors is arguably different from correcting errors of others, our erroneous examples with additional feedback that specifically targets the correction of performance errors seem to be a good candidate for creating the required learning opportunities.

Bibliography

[1] McLaren, B.M., Lim, S.J., Koedinger, K.R.: When and how often should worked examples be given to students? new results and a summary of the current state of research. In B. C. Love, K. McRae, V.M.S., ed.: Proceedings of the 30th Annual Conference of the Cognitive Science Sociaty, Austin, TX, Cognitive Science Society (2008) 2176–2181

[2] Trafton, J., Reiser, B.: The contributin of studying examples and solving problems. In: Proceedings of the Fifteenth Annual Conference of the Cognitive Science Society, - (1993) – http://www.citeseer.nj.nec.com/.

[3] Borasi, R.: Capitalizing on errors as "springboards for inquiry": A teaching experiment. Journal for Research in Mathematics Education **25**(2) (1994) 166–208

[4] Müller, A.: Aus eignen und fremden Fehlern lernen. Praxis der Naturwissenschaften **52**(1) (2003) 18–21

[5] Oser, F., Hascher, T.: Lernen aus Fehlern - Zur Psychologie des negativen Wissens. Schriftenreihe zum Projekt: Lernen Menschen aus Fehlern? Zur Entwicklung einer Fehlerkultur in der Schule, Pädagogisches Institut der Universität Freiburg, Schweiz (1997)

[6] OECD: International report PISA plus (2001)

[7] Siegler, R.: Microgenetic studies of self-explanation. In Granott, N., Parziale, J., eds.: Microdevelopment, Transition Processes in Development and Learning. Cambridge University Press (2002) 31–58

[8] Siegler, R., Chen, Z.: Differentiation and integration: Guiding principles for analyzing cognitive change. Developmental Science **11** (2008) 433–448

[9] Grosse, C., Renkl, A.: Finding and fixing errors in worked examples: Can this foster learning outcomes? Learning and Instruction **17** (2007) 612–634

[10] Melis, E., Goguadse, G., Homik, M., Libbrecht, P., Ullrich, C., Winterstein, S.: Semantic-aware components and services in ActiveMath. British Journal of Educational Technology. Special Issue: Semantic Web for E-learning **37**(3) (2006) 405–423

[11] Melis, E.: Design of erroneous examples for ActiveMath. In Ch.-K. Looi, G. McCalla, B.B., Breuker, J., eds.: Artificial Intelligence in Education. Supporting Learning Through Intelligent and Socially Informed Technology. 12th International Conference (AIED 2005). Volume 125., IOS Press (2005) 451–458

[12] Ohlsson, S.: Learning from performance errors. Psychological Review **103**(2) (1996) 241–262