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Learning from Erroneous Examples

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Abstract. We present students with common errors of others in the context of an intelligent tutoring system (ITS). We conducted two studies with students of different curriculum levels to measure the effects of learning through such erroneous examples. We report that erroneous examples with additional support can assist lower curriculum level students develop better meta-cognitive skills.

Keywords. Erroneous examples, fractions misconceptions, adaptive learning

1 Introduction

Erroneous examples (ErrEx) that is, worked solutions that include one or more errors that the student is asked to detect, explain, and/or correct have been rarely investigated as a teaching strategy in mathematics. On the contrary, correct worked examples have been the focus of research on mathematics and science problem solving, e.g. (4). Yet, the scarce work on ErrEx in mathematics has provided some evidence that studying errors can promote student learning (1). Grosse and Renkl's (2) empirical studies showed some learning benefits of studying incorrect examples on transfer, but only for high-competent learners.

We investigate ErrEx with and without help and are interested in how students react when they receive help in the context of an ITS. This novel design relies on the intelligent technology developed in ActiveMath (3), a web-based learning environment for mathematics. The help supports students who are not accustomed to working with ErrEx and may not have the required skills to analyze, and reflect upon such examples. We aim to find out if and when erroneous examples can foster students problem-solving, concept understanding, and transfer abilities, as well as the meta-cognitive competencies of error detection/ awareness and error correction.

2 Lab Studies with Erroneous Examples in ActiveMath

We conducted lab studies with German 6th, and 7th and 8th-graders. There were three conditions. No-ErrEx (NOEE) was the control and included standard fraction exercises of the form 3/4+5/7, but no ErrEx in the intervention. ErrEx-Without-Help (EEWOH) included standard exercises, and erroneous examples but with no additional help, whereas ErrEx-With-Help (EEWH) additional help on the ErrEx. The design included pretest, familiarization, intervention, and posttest. In the intervention, all groups solved six sequences of three items: two standard exercises and either a third exercise or an ErrEx on fractions. Word problems were also included (Figure 1). 7th and 8th-graders also solved *modeling exercises*, which required them to use fraction operators to represent a word problem. The online ErrEx that were used included two phases: error detection and error correction. Figure 1 displays the first phase. The task is: “Jan rides his bike for 1/6 of his way to school, then drives with the tram 4/5 of the way and finally goes the rest of the way on foot. He wants to know what fraction of the way he goes on foot.” In this phase, students select the erroneous step. There are three types of unsolicited feedback: (i) Minimal feedback is both flag and verbal. (ii) Error detection and awareness (EAD) feedback, intends to foster meta-cognitive skills (e.g., “The result, way on foot = 5 1/30 cannot be correct. The trip with the bus is already 4/5, so the way on foot must be less than 1/5 of the whole way".) (iii) Multiple choice questions (MCQs) attempt to help students understand the underlying principles of the task through questions like “Why is the 4th step wrong?” EAD and MCQs were only available to EEWH condition. In the second phase, students are prompted to correct the error. All conditions received minimal feedback and the whole correct answer after one wrong attempt. The posttest consisted of similar exercises as the intervention, a transfer exercise (four-fraction addition), and ErrEx with conceptual questions to test students’ error detection skills as well as underlying principles of fractions (e.g. “What mistake did Oliver make?”).

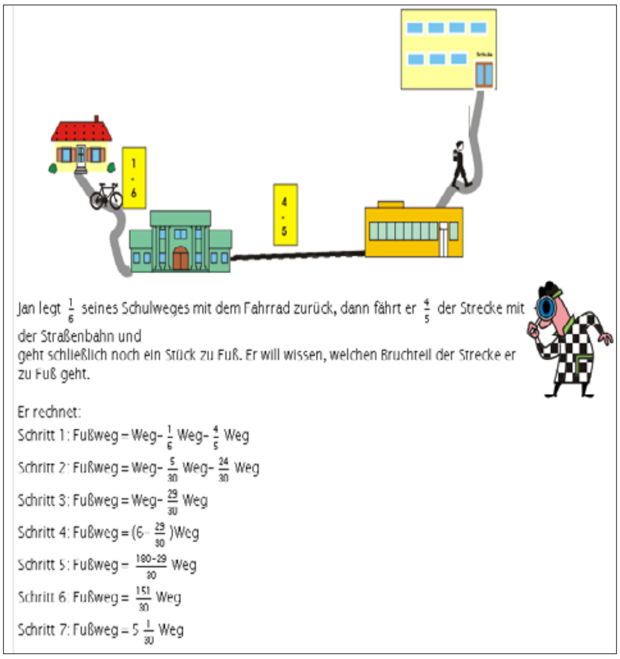

Fig. 1. Phase 1: Error detection

6th-GradeResults. Twenty-three (23) paid volunteers participated in the lab studies, (EEWH=8, EEWOH=7, NOEE=8). The mean of their term-grade in math was 2.04 (best=1, fail=6), so the participants were high prior knowledge students. As a result, there was a ceiling effect in the standard exercises (post-pre-diff, *M* =5.04). EEWH had the highest score in all ErrEx scores (cf. Table) and the same score with NOEE in the transfer exercise. Additionally, the total score on ErrEx that includes finding and correcting the error and conceptual questions, is significantly higher in EEWH than in

	Descriptive Statistics 6th-Grade			*Descriptive Statistics 7th-8th-Grade*		
Condition	EEWH	EEWOH	NOEE	EEWH	EEWOH	NOEE
Txpe of Score	*mean(sd)%*	*mean(sd)%*	*mean(sd)%*	*mean(sd)%*	*mean(sd)%*	*mean(sd)%*
EEfind	91.7(15.4)*	71.4(35.6)^	62.5(27.8)	68.7(34.7)	75.0(13.4)^	90.6(12.9)*
EEcorrect	80.2(12.5)*	75.0(21.0)^	68.7(25.9)	60.9(30.2)^	57.8(20.0)	71.9(24.8)*
EE-ConQuest	64.6(25.5)*	60.2(11.0)^	8.3(21.2)	55.2(46.5)	62.5(12.6)*	61.5(19.4)^
EE-total	73.1(18.3)*	5.5(27.8)	51.2(20.8)^	59.1(39.3)	64.1(1.9)^	69.4(17.3)*
Transfer	75.0(46.2)*	71.4(48.8)^	75.0(46.3)*	45.2(45.8)^	38.0(36.0)	67.3(28.5)*
Post-pre-diff	-2.1(33.6)	1.2(21.7)^	2.1(23.9)*	2.4(24.4)^	1.1(21.6)	7.0(18.0)*

Note: *=best , ^=middle learning gains (no marking for learning loss)

NOEE ($t(14)=2.227$; $p = 0.043$). With the term-grade as covariate, there are also significant differences in all ErrEx scores between EEWH and EEWOH.

7th-8th-Grades Results. Twenty-four (24) students participated, eight in each condition. Their mean term-grade in math was 2.88. Surprisingly NOEE did better in almost all scores, although the differences are small and not significant (cf. Table). An interesting result is that the term-grade is a significant covariate on conceptual questions (p=0.047) but not on problem-solving. A possible interpretation is that the math level influences conceptual understanding more than problem-solving of fractions at this class level. The study also revealed that a significant number of students could find the error but not correct it ($t(23)=4.89$, p= 0,000<0.001). This may mean that although students have declarative knowledge that helps them identify rule violations, they still have knowledge gaps that are exposed when they correct errors.

Conclusion. Our results support the hypothesis that meta-cognitive skills are fostered by the use of ErrEx and additional help for high-competent 6th-graders, but not for 7th/8th-graders, where prior knowledge seems to play a crucial role. They also indicate a possible dissociation, described by Ohlsson (5), between declarative knowledge (finding rule-related errors) and practical knowledge (correcting errors).

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