Do students improve their metacognitive skillfulness when they receive feedback?

Jacqueline Gutman, New York University
Thomas Bishop, Pearson HE

Examining context-specific metacognitive ability with a metacognitive KC model

Mentor #1: Chris MacLellan, Carnegie Mellon University
Mentor #2: Matthew Bernacki, University of Nevada Las Vegas

Rationale

Learners do not intuitively know how to best use online learning environments, often engaging in behaviors that will lead to best short-term performance or completion of the unit at the expense of learning (Scheines, Leinhardt, Smith, & Cho, 2005). Unfortunately learners are placed in control when using intelligent tutoring systems without metacognitive support (Aleven & Koedinger, 2000). Intelligent tutoring systems can be extended with a Help Seeking Tutor to identify and potentially correct faulty metacognitive behavior in learners (Roll, Baker, Aleven, & Koedinger, 2005).

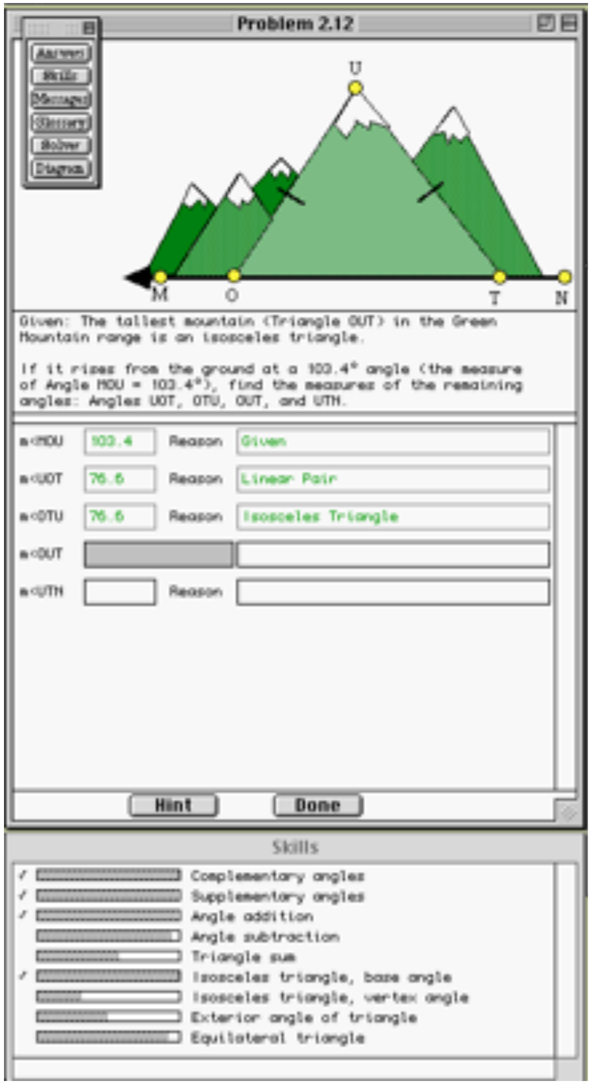
Research Questions

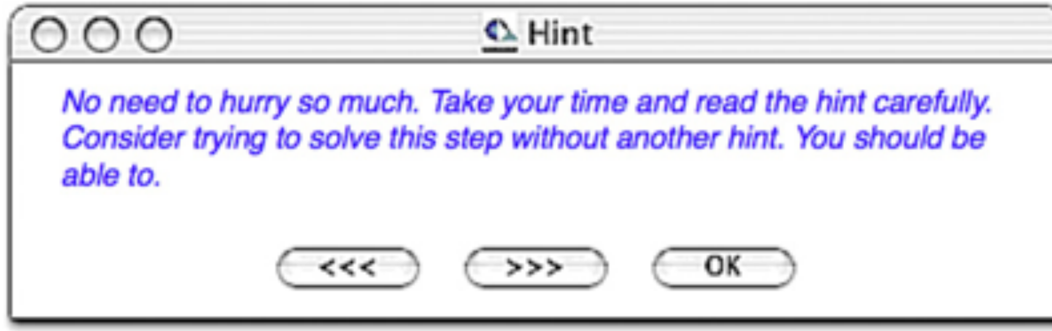
Do students improve the appropriateness of their problem-solving behavior (i.e. help seeking vs. attempting a step) when they receive metacognitive interventions? Is this improvement context specific or domain general?

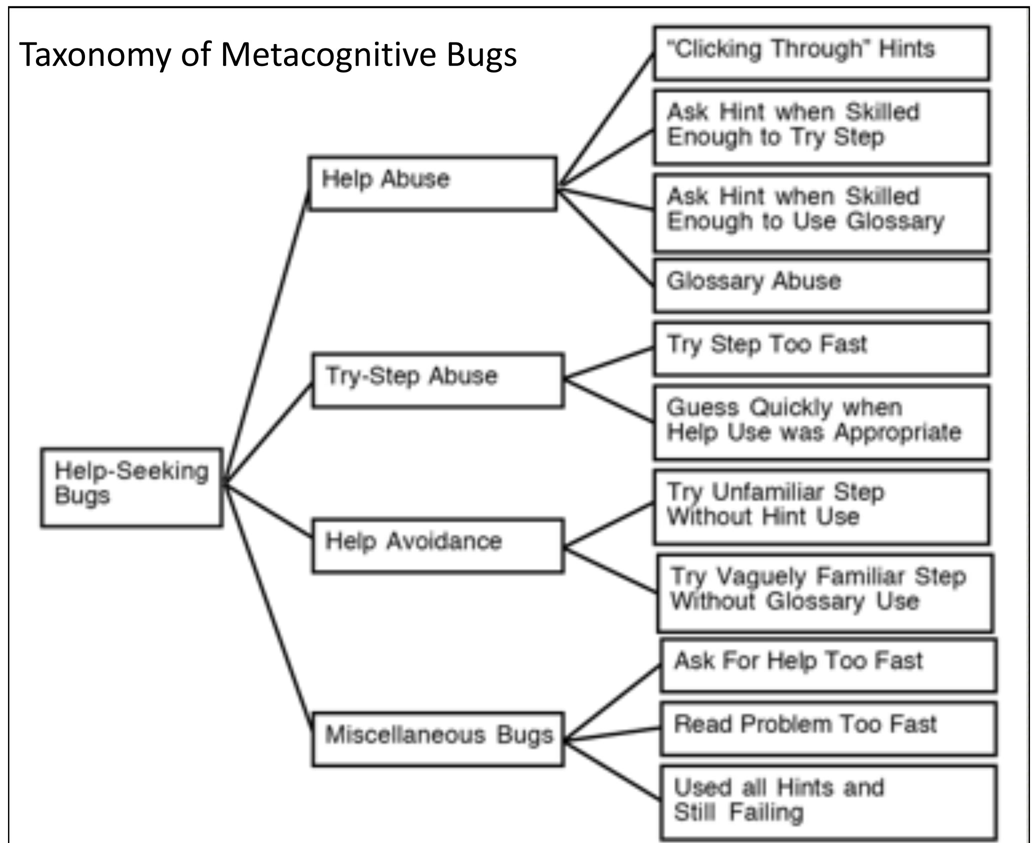
Does improvement in specific metacognitive abilities generalize to improvement in other metacognitive skills or does learning occur independently in distinct metacognitive skills?

Are metacognitive skills best modeled at the transaction level or step level (does learning occur between transactions within a cognitive step)?

The PACT Geometry Tutor with Help-Seeking Tutor







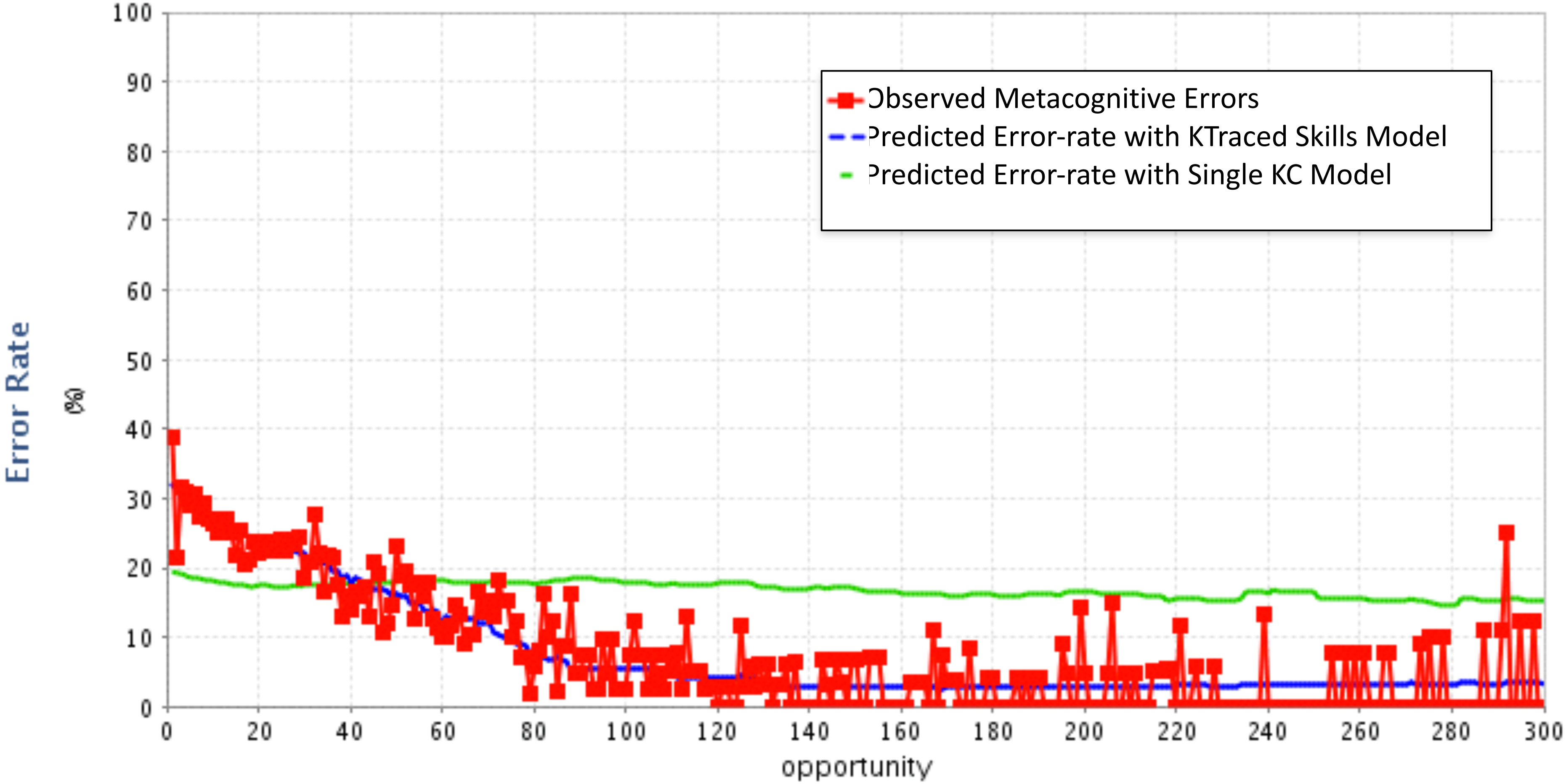
Aleven & Koedinger, 2000.
Roll, et al., 2011.
Aleven et al., 2004.

Extending the cognitive model to the metacognitive domain

Results presented here are based on data collected using the The PACT Geometry Tutor with 23 students in 1998 at Fox Chapel High School in Pittsburgh, PA.

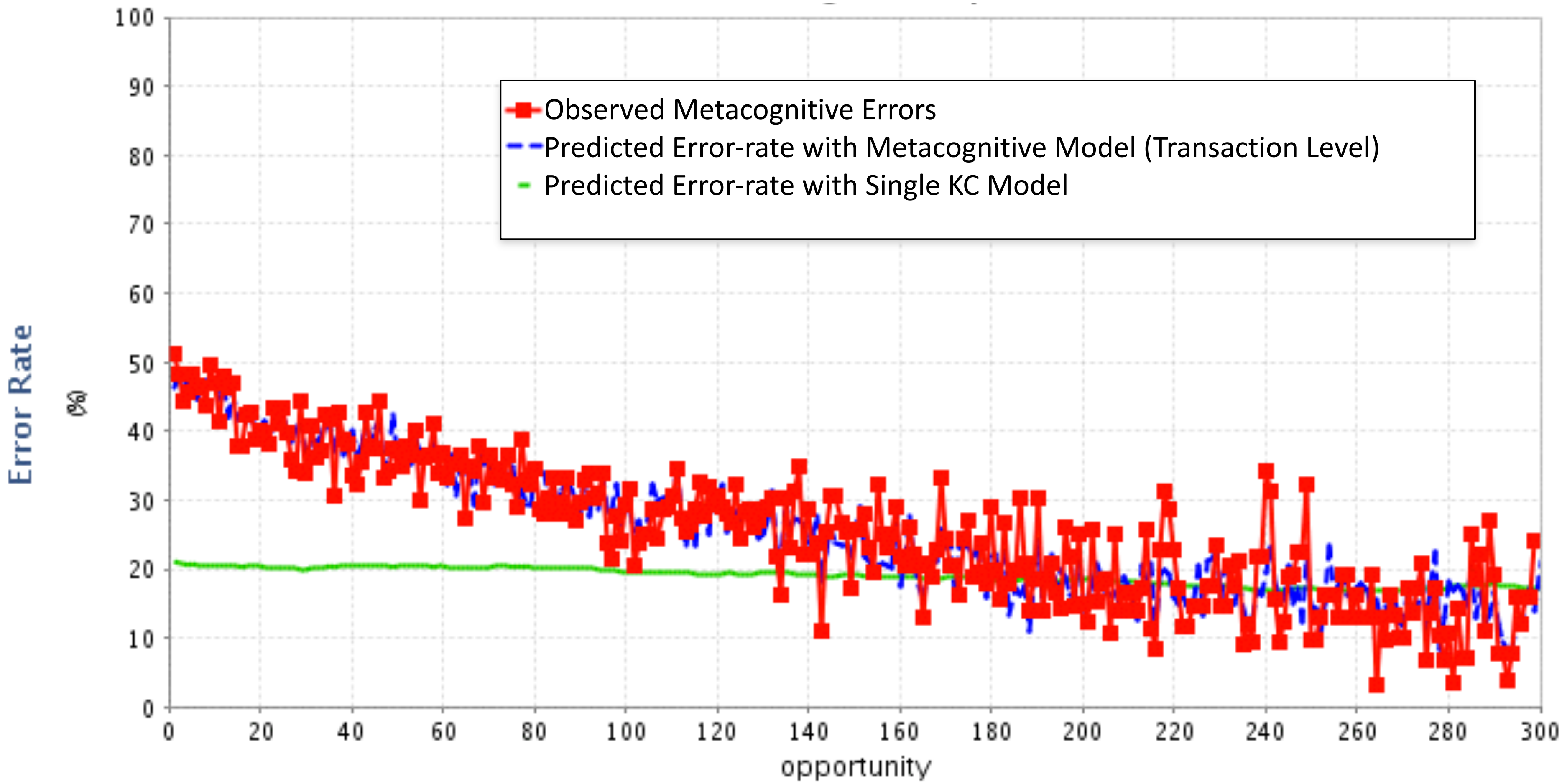
	Traditional Cognitive Model	Metacognitive Model
Outcome	Cognitive correctness according to cognitive model	Metacognitive correctness according to metacognitive model
KCs	Cognitive KCs (angle-addition)	Metacognitive and cognitive KCs (try-step or ask-for-hint-low-skill)
Steps	Cognitive step	Cognitive step
First attempts	First attempt at a step	First attempt at new or same step after a correct metacognitive action on previous transaction
Unit of analysis	Step-level KCs	Transaction-level KCs
Number of KCs	varies	25 Metacognitive KCs and 27 KTraced (cognitive) KCs

KTraced skills model of metacognitive learning



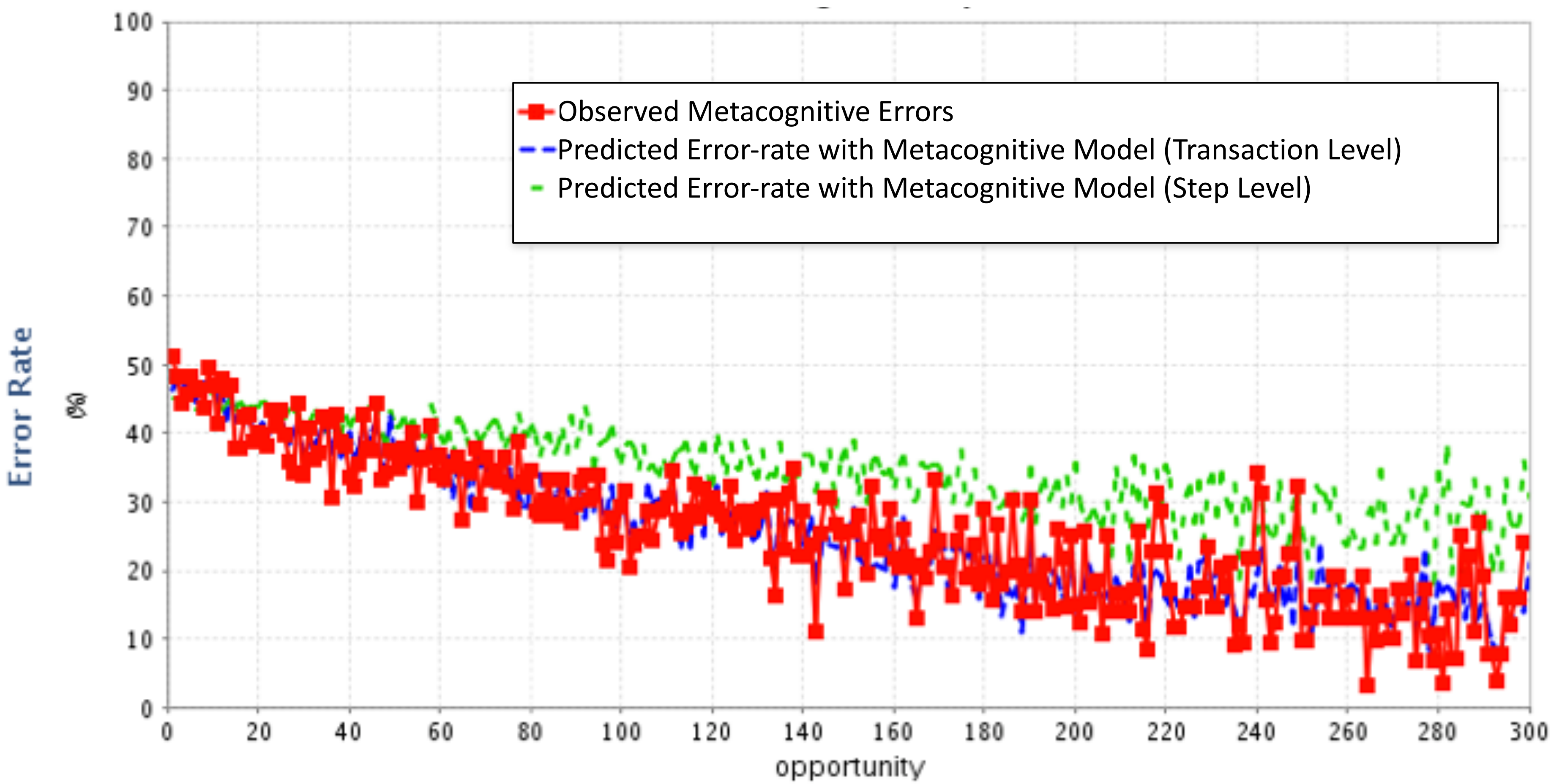
Over successive opportunities at the same cognitive skill, metacognitive errors decline in a context-specific fashion. If we consider all steps to be opportunities at learning the same cognitive KC, we see no evidence of learning metacognitive skills.

Metacognitive paths model of metacognitive learning



Over successive opportunities at the same metacognitive skill, metacognitive errors decline in a context-specific fashion. If we consider all steps to be opportunities at improving metacognitive skillfulness more generally, we see no evidence of improved metacognitive ability. The metacognitive model fits the data better and is more robust compared to the KTraced Skills model of metacognitive performance.

Transaction vs. step roll-up of metacognitive models



The step level model overestimates metacognitive errors. Within a single step multiple metacognitive transactions are rolled up and each step may feature an opportunity for up to eight metacognitive KCs. When we model this as multiple-KCs-per-step, the learning rate is overly conservative and the model underestimates learners' improved metacognitive skillfulness compared to the transaction-level model.

Comparing model fit

Model Name	KCs	AIC	BIC	RMSE (Student stratified)	RMSE (Item stratified)	RMSE (Unstratified)
Metacognitive (transaction level)	25	9995.64	10556.96	0.279	0.270	0.270
Metacognitive (step level)	24	13080.52	13080.52	0.347	0.323	0.317
KTraced Skills (transaction level)	27	13343.47	13952.22	0.389	0.324	0.322
KTraced Skills (step level)	27	13577.04	14185.80	0.450	0.335	0.324
Single-KC	1	17517.11	17714.76	0.383	0.371	N/A

The transaction level unit of analysis is most appropriate for analyzing metacognitive outcomes. The metacognitive model fits better than the KTraced Skills model. The single KC model fits the observed behavior exceptionally poorly.

Rate of learning by path in metacognitive cycle

Metacognitive Path	Intercept	Slope	Frequency
NEW-CYCLE * THINK-ABOUT-STEP-DELIBERATELY * TRY-STEP * STEP-WAS-WRONG	0.92	0	3628
NEW-CYCLE * THINK-ABOUT-STEP-DELIBERATELY * TRY-STEP * STEP-WAS-CORRECT	0.9	0.001	16263
CONSIDER-HINT * READ-HINT-DELIBERATELY * TRY-STEP-AFTER-HINT-MED-SKILL * STEP-WAS-WRONG	0.58	0.009	1414
NEW-CYCLE * THINK-ABOUT-STEP-DELIBERATELY * SEARCH-THE-GLOSSARY-MED-SKILL	0.58	0.004	2062
CONSIDER-HINT * READ-HINT-DELIBERATELY * HELP-TRY-STEP-IMMEDIATELY-AFTER-ALL-HINT * STEP-WAS-WRONG	0.49	0.005	3961
NEW-CYCLE * THINK-ABOUT-STEP-DELIBERATELY * ASK-HINT-DUE-TO-LOW-SKILL	0.48	0.007	2486
CONSIDER-HINT * READ-HINT-DELIBERATELY * TRY-STEP-AFTER-HINT-HIGH-SKILL * STEP-WAS-WRONG	0.41	0.019	5371
CONSIDER-NEXT-ACTION * THINK-ABOUT-STEP-DELIBERATELY * TRY-STEP * STEP-WAS-WRONG	0.39	0.004	2323
CONSIDER-NEXT-ACTION * THINK-ABOUT-STEP-DELIBERATELY * REREAD-HINT	0.35	0	112
CONSIDER-NEXT-ACTION * THINK-ABOUT-STEP-DELIBERATELY * ASK-HINT-AFTER-ATTEMPTS	0.28	0.003	1714
CONSIDER-HINT * READ-HINT-DELIBERATELY * ADDITIONAL-HINT-HIGH-SKILL	0.26	0.009	1569
CONSIDER-HINT * READ-HINT-DELIBERATELY * TRY-STEP-AFTER-HINT-HIGH-SKILL * STEP-WAS-CORRECT	0.16	0.006	693
CONSIDER-HINT * READ-HINT-DELIBERATELY * ADDITIONAL-HINT-LOW-SKILL	0.16	0.005	5552
CONSIDER-NEXT-ACTION * THINK-ABOUT-STEP-DELIBERATELY * SEARCH-THE-GLOSSARY-MED-SKILL	0.14	0.013	814
CONSIDER-NEXT-ACTION * THINK-ABOUT-STEP-DELIBERATELY * ASK-HINT-LOW-SKILL-TRIED-BEFORE	0.12	0.003	2103
CONSIDER-NEXT-ACTION * THINK-ABOUT-STEP-DELIBERATELY * TRY-STEP * STEP-WAS-CORRECT	0.12	0	1011
CONSIDER-HINT * READ-HINT-DELIBERATELY * TRY-STEP-AFTER-HINT-MED-SKILL * STEP-WAS-CORRECT	0.11	0.013	276
CONSIDER-HINT * READ-HINT-DELIBERATELY * HELP-TRY-STEP-IMMEDIATELY-AFTER-ALL-HINT * STEP-WAS-CORRECT	0.1	0	1452
CONSIDER-HINT * READ-HINT-DELIBERATELY * ADDITIONAL-HINT-MEDIUM-SKILL	0.07	0.021	4013
CONSIDER-NEXT-ACTION * THINK-ABOUT-STEP-DELIBERATELY * ASK-HINT-DUE-TO-LOW-SKILL	0.01	0.381	48
CONSIDER-NEXT-ACTION * BUG1-THINK-ABOUT-STEP-QUICKLY DECIDE-ACTION-TO-TAKE * TRY-STEP-NO-HINTS-LEFT * STEP-WAS-CORRECT	0.08	0.121	23
CONSIDER-NEXT-ACTION* THINK-ABOUT-STEP-DELIBERATELY * TRY-STEP-AFTER-ALL-HINTS * STEP-WAS-CORRECT	0.48	0	9
CONSIDER-NEXT-ACTION * THINK-ABOUT-STEP-DELIBERATELY * TRY-STEP-AFTER-ALL-HINTS * STEP-WAS-WRONG	0	0	6
CONSIDER-NEXT-ACTION * THINK-ABOUT-STEP-DELIBERATELY * TRY-STEP-AFTER-GLOSS-MED-SKILL * STEP-WAS-CORRECT	0	314.073	1

Paths in gray occurred in fewer than 100 observations and were discarded from subsequent analysis.

Exemplar paths for fast, slow, and negligible learning

All slopes were quite small; however, with transaction-level analyses, opportunity counts were sufficiently high for learning to proceed even with an ostensibly small slope on the fitted learning curve.

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