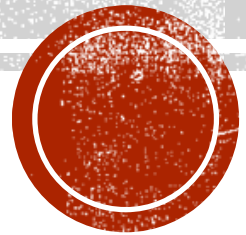
Predicting Students' Unproductive Failure on Intelligent Tutors in Adaptive Online Courseware

Seoyeon Park and Noboru Matsuda

Texas A&M University



Mastery learning in Intelligent Tutoring Systems (ITSs)

- Learning by "Doing" (Anderson, 1996)
  : Students will master a skill if they practice on that skill repetitively
  : Providing problems with different wording or numbers repetitively

- Knowledge tracing to implement mastery learning (Corbett & Anderson, 1995)
  : a criterion knowledge probability for mastery is 0.95

- Concerns

(Cen, Koedinger, & Junker, 2007; Baker, Gowda, & Corbett, 2011)

  - Lose Interest
  - Waste of learning time
  - Frustration
  - Lose confidence

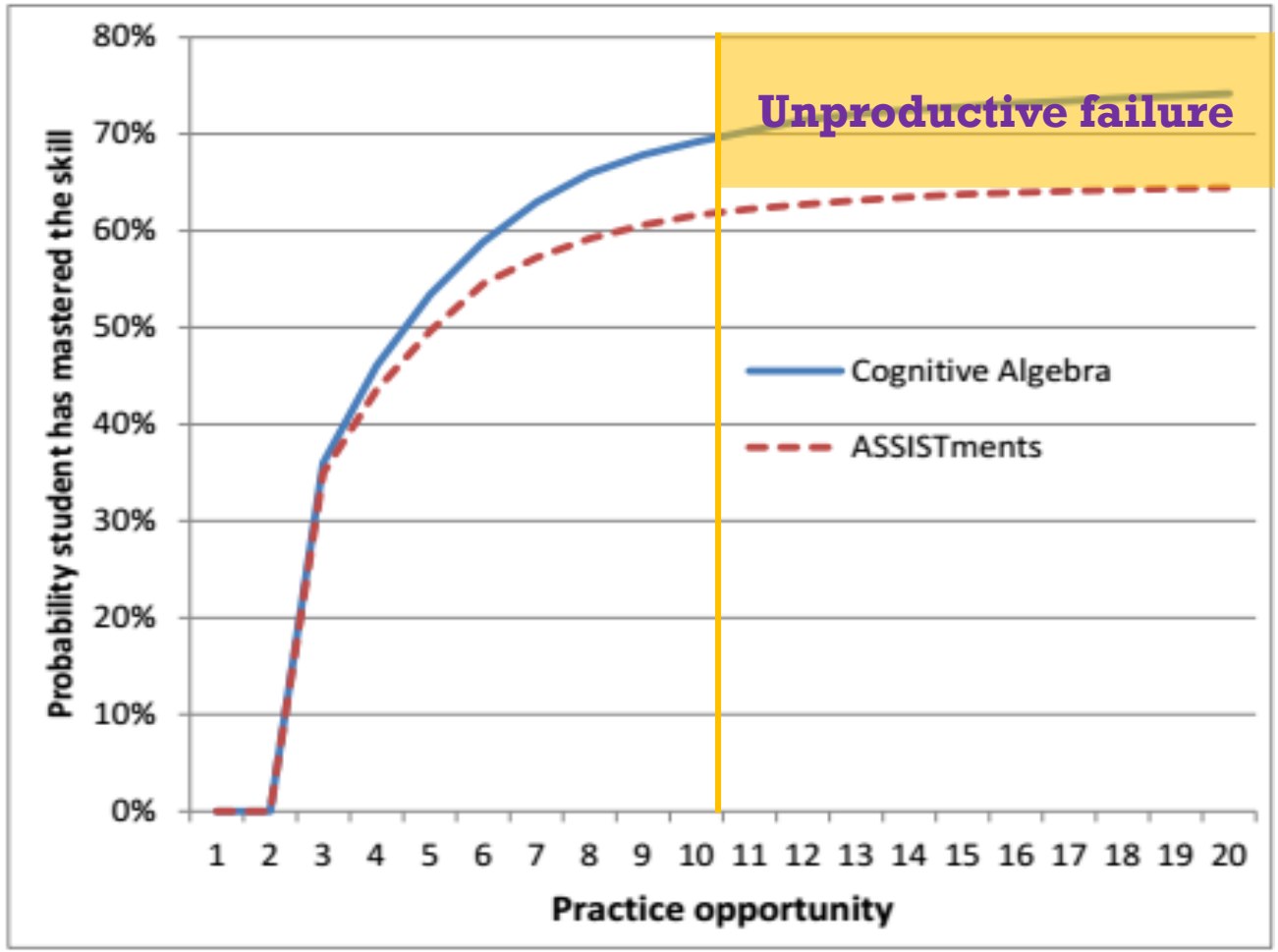
Unproductive failure in ITSs (Wheel-spinning)

- Some students just cannot get it with "learning by doing" approach
- Learning cycle = Wheel spinning phenomena

- "Those who fail to get mastery on a skill within 10 practice opportunities" (Beck & Gong, 2013)
  - Definition of "Mastery"

    : three consecutive correct answers in a row

Unproductive failure in ITSs (Wheel-spinning)



(Beck & Gong, 2013)

Wheel-spinning detection & prediction

- Predicting ”Wheel-spinning” is important because…

We don’t want to waste a leaner’s time.

We don’t want a learner to lose interest.

We don’t want a leaner to feel depressed.

- Generic wheel-spinning detector (Beck &Gong, 2015)
  - Using several variables : correct response number, hint use, response speed, skill difficulty and others.

- Wheel-spinning predictor

  (Matsuda, Chandrasekaran, and Stamper, 2016)
  - a combination of the probability of mastery based on Bayesian knowledge tracing, and a neural-network model.

Problems

- **Low recall rate (25~50%)** of existing models

Table 4 Precision and recall on wheel-spinning on test data of the CAT and ASSISTments models

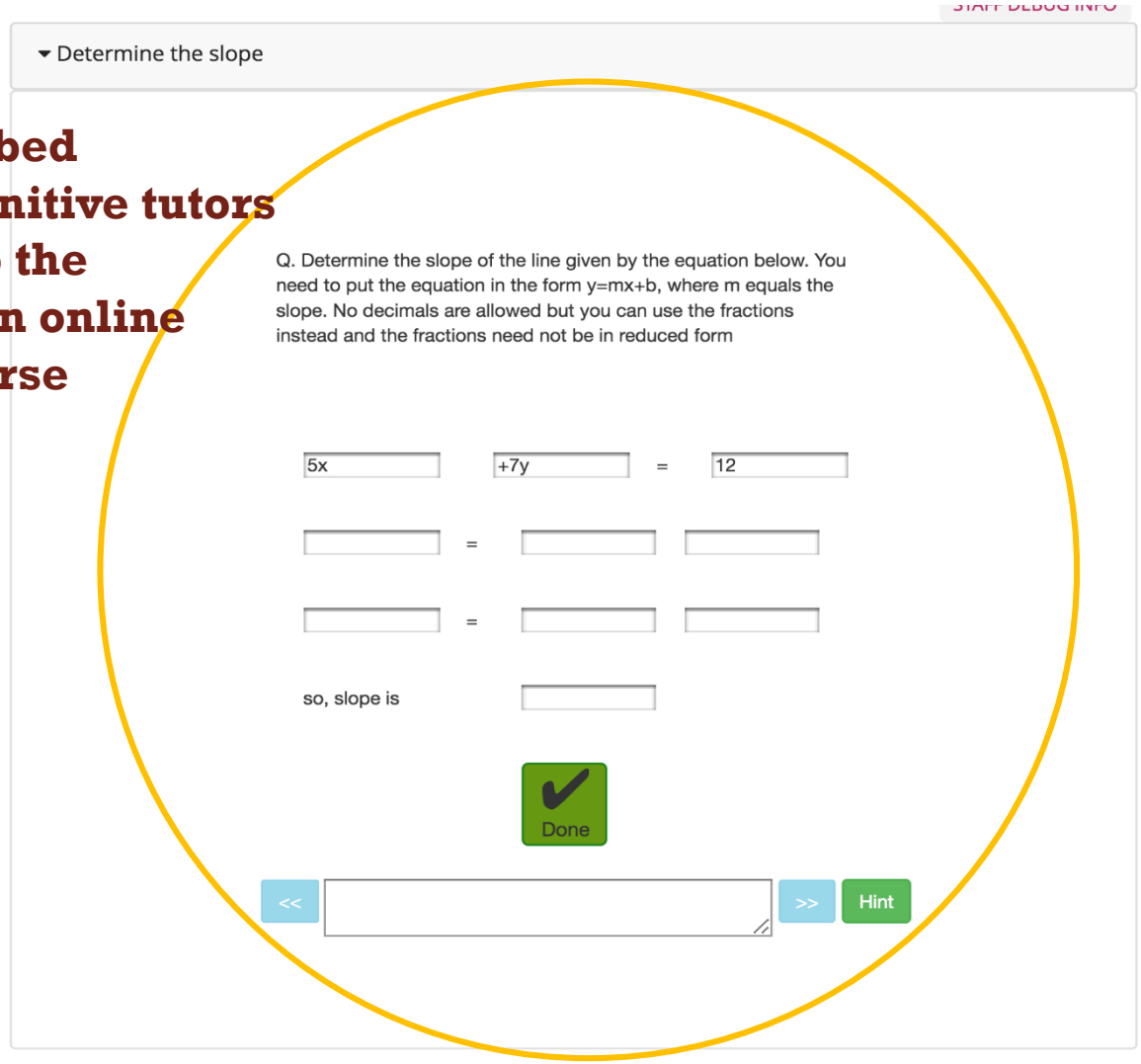
	Precision	Recall
The CAT	71.1%	52.7%
ASSISTments	76.6%	53.1%

(Beck & Gong, 2015)

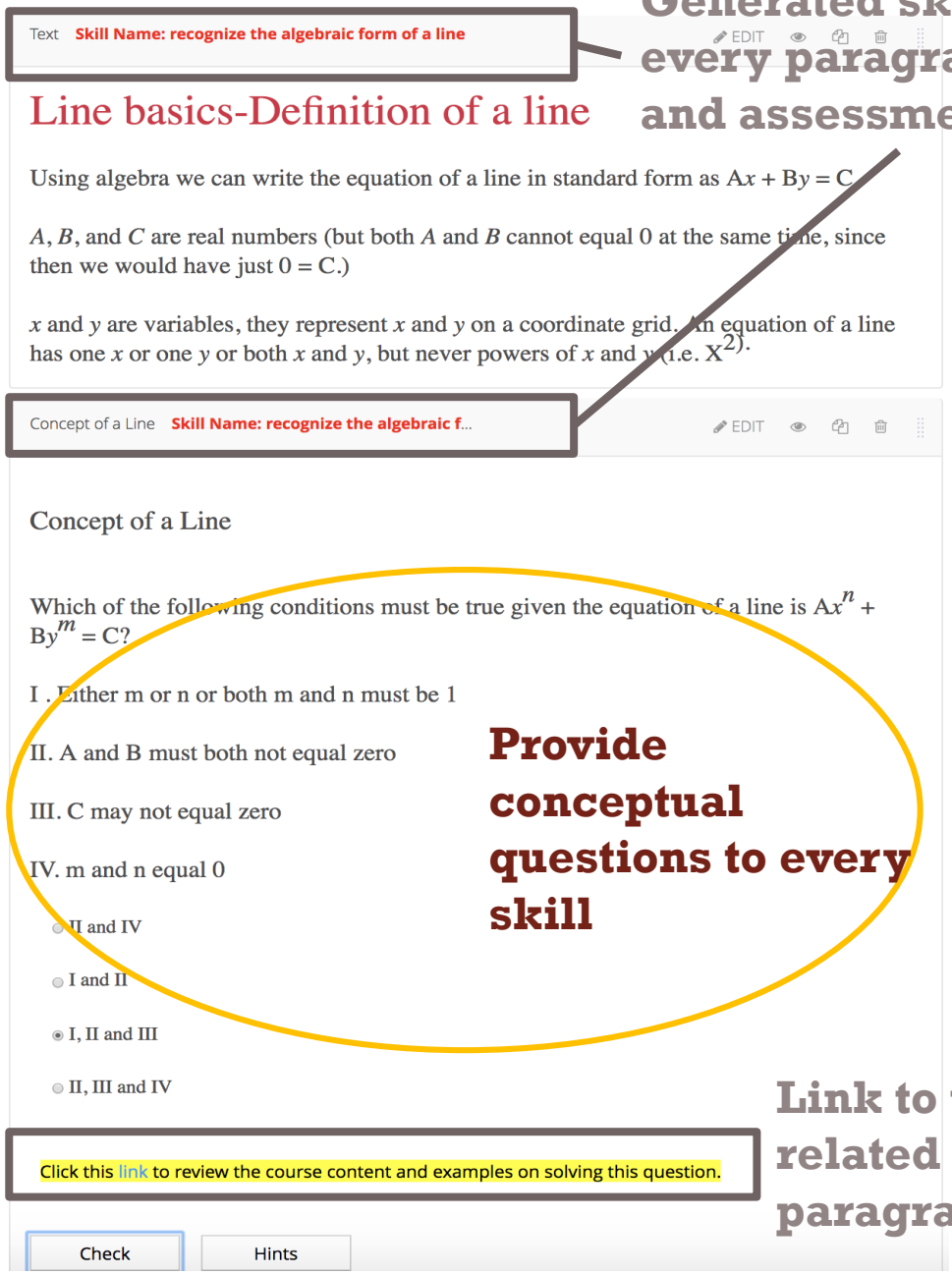
- **Skill level vs Problem level**
  - *For the wheel-spinning prediction for an adaptive online courseware, Cyberbook, can we use* "problem" *as a unit of analysis?*

Cyberbook
-adaptive online courseware

Embed cognitive tutors into the open online course



Generated skills for every paragraphs and assessments



Provide conceptual questions to every skill

Link to the related paragraph(s)

Cyberbook
-adaptive online courseware

Q. Determine the slope of the line given by the equation below. You need to put the equation in the form y=mx+b, where m equals the slope. No decimals are allowed but you can use the fractions instead and the fractions need not be in reduced form

Determine slope from ax+by=c

6y +8x = -55

b1 6y = b2 -8x b3 -55

b4 y = b5 -8/6x b6 -55/6

so, slope is b7 -8/6

b1, b2 Isolate y
b3 copy down
b4 ~ b6 divide
b7 Determine slope from y=ax +b

Done

<< >> Hint

Skills	Cognitive Tutors											
	1	1(2)	2	3	4	5	5(2)	5(3)	6	6(2)	6(3)	7
copy down	1	1	1	1		1			1			
add						1		1	1			
subtract					1	1			1			
			(omitted)									
isolate y/ solve 'in terms of y' (algebraic manipulation)	1	1	1	1								1
determine a y-intercept by setting x=0	1											
determine a y-intercept from given info				1								
determine a y-intercept from y=mx+b		1										
determine slope from y= mx+b			1	1								
determine slope from ax+by=c												1
write the equation of line: y=mx+b				1								
read the x, y-coordinates of a point					1							
find the distance between two points						1			1			
find the distance from a point to a line					1							
Pythagorean theorem								1				
read the length of legs					1		1	1		1	1	
calculate the area of the square									1	1		
calculate the area of triangle										1		
use 3-4-5 or 5-12-13 right triangle ratio							1					
use 45-45-90 or 30-60-90 special triangles											1	
know when ax+by=c is parallel												1
know when parallel lines have no solution												1

associated skill

representative skill

Solutions

- **Low recall rate (25~50%)** of existing models

> Gradient boosting

- **Skill level vs Problem level**
  - *For the wheel-spinning prediction for an adaptive online courseware, Cyberbook, can we use* "problem" *as a unit of analysis?*

> SMART

Research Questions

1) How accurately can we predict wheel-spinning at the problem level?
2) How early can we detect wheel-spinning at the problem level?

Data preprocessing

DataShop @CMU
a data analysis service for the learning science community

- 'Cog Model Discovery Experiment Spring 2010', from DataShop.
- 49 skills forming 45,597 observations done by 123 students in the 'KTracedSkills' model in this dataset.
- 5,279 student-skill pairs.

Data preprocessing : SMART

- Using SMART to create Problem type
  - SMART is an AI technology that can compute the similarity among words within the text and extract a key word.
  - We input hint message of each intelligent tutor and set an arbitrary k number; k=25, 50, 75, 100.
  - After SMART generates problem types, those problem type models were validated with the DataShop knowledge component model.

Data preprocessing : SMART

Hint messages → skills

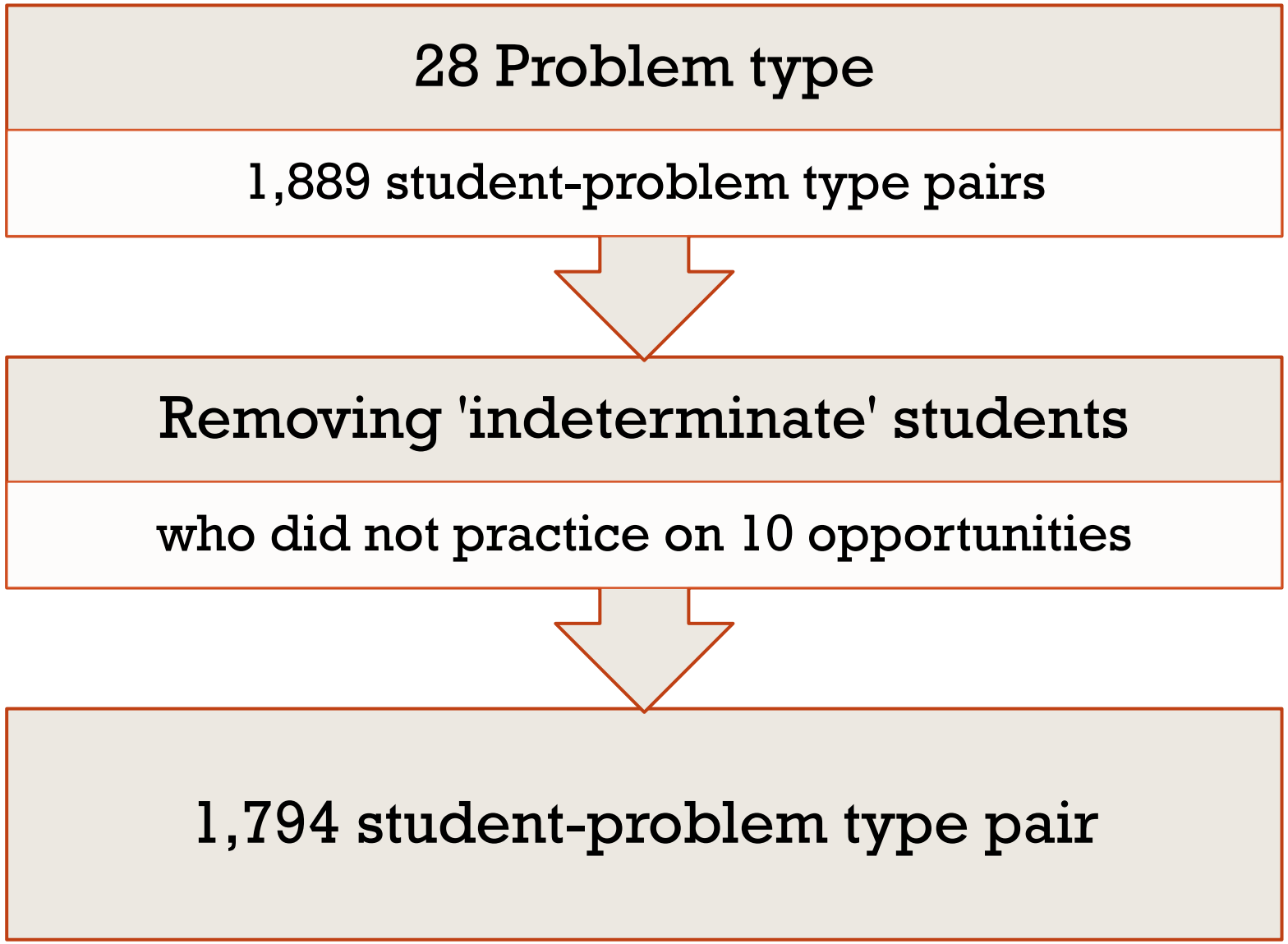
Tutor number	Text used in Assessments	SMART
3	Copy down the equation. Enter 2. Box 2: Enter -5 . Box 3: Enter 10. Box 4: Our goal is to write equation of a line in slope/intercept form: y=mx + b. When using this form, you will need to determine the slope of the line, m, and the y-intercept, b. It was mentioned that the lines are parallel. To find the slope of our new line, recall that parallel lines have the same slope. Thus, the slope of the given equation will also be the slope of line 1. (…)	equation
1	Notice that when any curve intersects the y axis, the x-coordinate of the point of intersection is 0. Setting x=0 and solving for y, will give you the y-coordinate where the line crosses the y axis . Set x = 0. Box 2: Enter 0. Box 3 Replace x with 0 in the given equation. 2(0)+4y=16 (…)	equation
1(2)	Copy down the problem. Enter 2. Box:2 Enter 4. Box 3: Enter 16. Box 4: The place where a curve crosses the y-axis is called the y-intercept, often referred to as b in the equation y=mx+b, (recall this is called the slope-intercept form of a line where m is the slope, and b is the y-intercept) (…)	equation
2	Copy the problem. Enter 8. Box 2: Enter -2. Box 3: Enter 4. Box 4: By solving the given equation for y, we are putting the line in slope intercept form y = mx + b. Then we can read the slope, m, from the equation. To solve for y, you need to get rid of the -2x and the 8 next to y. First move the 2x to the other side by adding 2x to both sides. (…)	equation
4	We need to find the shortest distance from a point to a line, which is the perpendicular line segment drawn from the point to the line. Because AB is a vertical line, the line perpendicular to it will be horizontal. So we need the length of the horizontal line segment from point C to line AB. Since the distance from a point to a vertical or horizontal line can be found by the simple difference of coordinates, we just can subtract the x-coordinates from C to AB. (…)	line
5(2)	One way to find the distance between points A and B, is to make them the hypotenuse of a right	Right

Data preprocessing : SMART

Comparison of SMART generated problem type models

Model name	Problem types	Observations with Problem types	AIC	BIC	RMSE (student stratified)	RMSE (item stratified)
SMART k=25	17	85,115	46,986.00	48,454.30	0.2731	0.271
SMART k=50	28	85,115	46,787.87	48,461.83	0.2726	0.271
SMART k=75	40	85,115	47,114.50	49,012.91	0.2744	0.272
SMART k=100	39	85,115	47,145.30	49,025.00	0.2735	0.272
KtracedSkills	49	41,756	29,096.28	31,005.13	0.3337	0.324

Data preprocessing



Features

- Outcome

: whether a student shows mastery (M) or wheel-spinning (W) on a problem type within 10 opportunities

- Predictors
  - Students' performance on each problem type
  - Problem type difficulty
  - Maximum number of using hints
  - Sum_duration (response time)

Prediction models
- A Basic model

- **A basic wheel-spinning prediction at the problem level**
  - trained a logistic regression using the combination of four features with ten-fold cross validation
- Overall percent correct is 92.75% and AUC is 0.916
- However, precision rate is 60% and recall rate is 33.65% on average.

Precision and Recall rates of a basic model per practice opportunity

	opp3	opp4	opp5	opp6	opp7	opp8	opp9
Precision	0.358	0.440	0.551	0.619	0.666	0.755	0.814
Recall	0.0798	0.176	0.230	0.285	0.417	0.612	0.554

Prediction models - Upgraded model

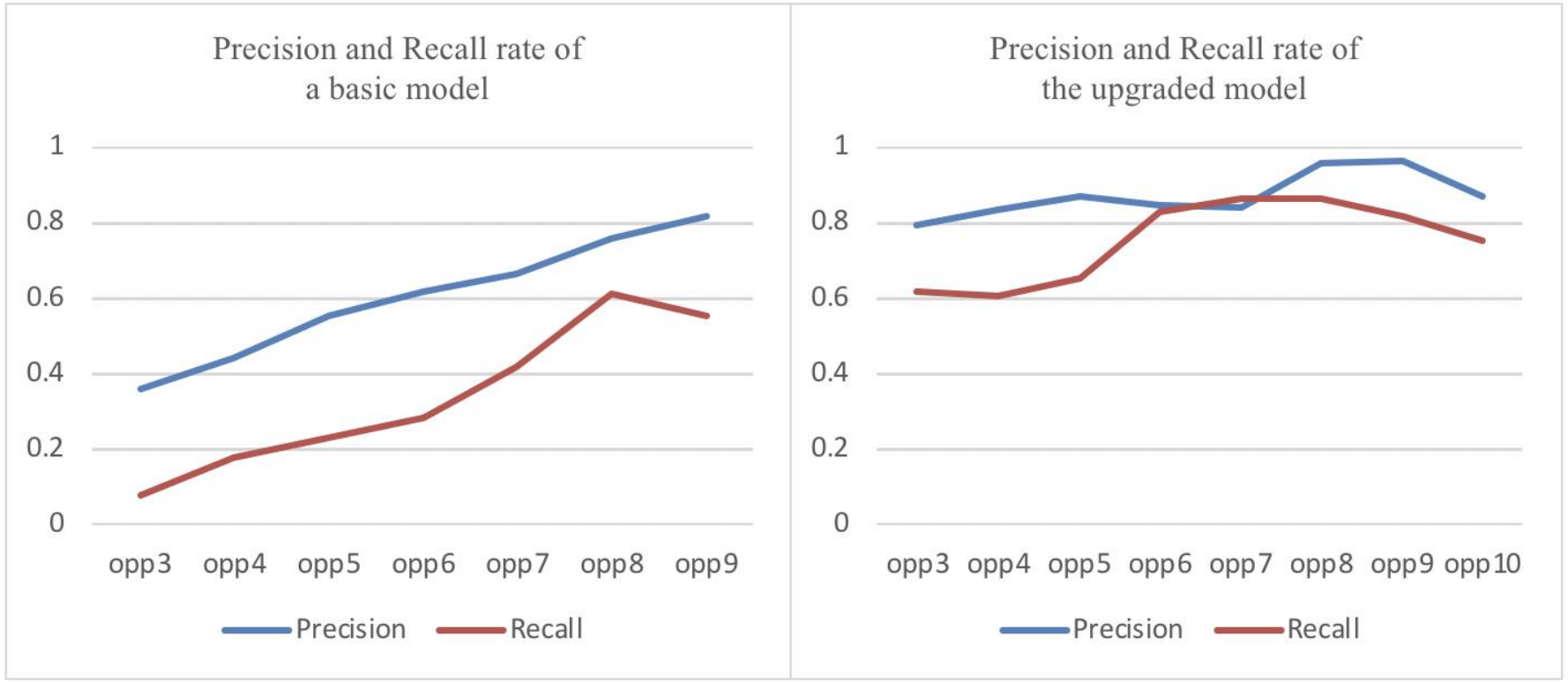
- **The upgraded prediction model at the problem level**
  - trained a gradient boosted decision tree using the combination of four features with ten-fold cross validation
- Overall percent correct is 96.90% and AUC is 0.97
- Precision rate is 87% and recall rate is 75% on average.
- 65% recall rate on students' fifth opportunity and over 80% on the sixth opportunity.

Precision and Recall rates of the upgraded model per practice opportunity

	opp3	opp4	opp5	opp6	opp7	opp8	opp9
Precision	0.792	0.834	0.867	0.843	0.840	0.958	0.963
Recall	0.616	0.606	0.651	0.829	0.865	0.864	0.813

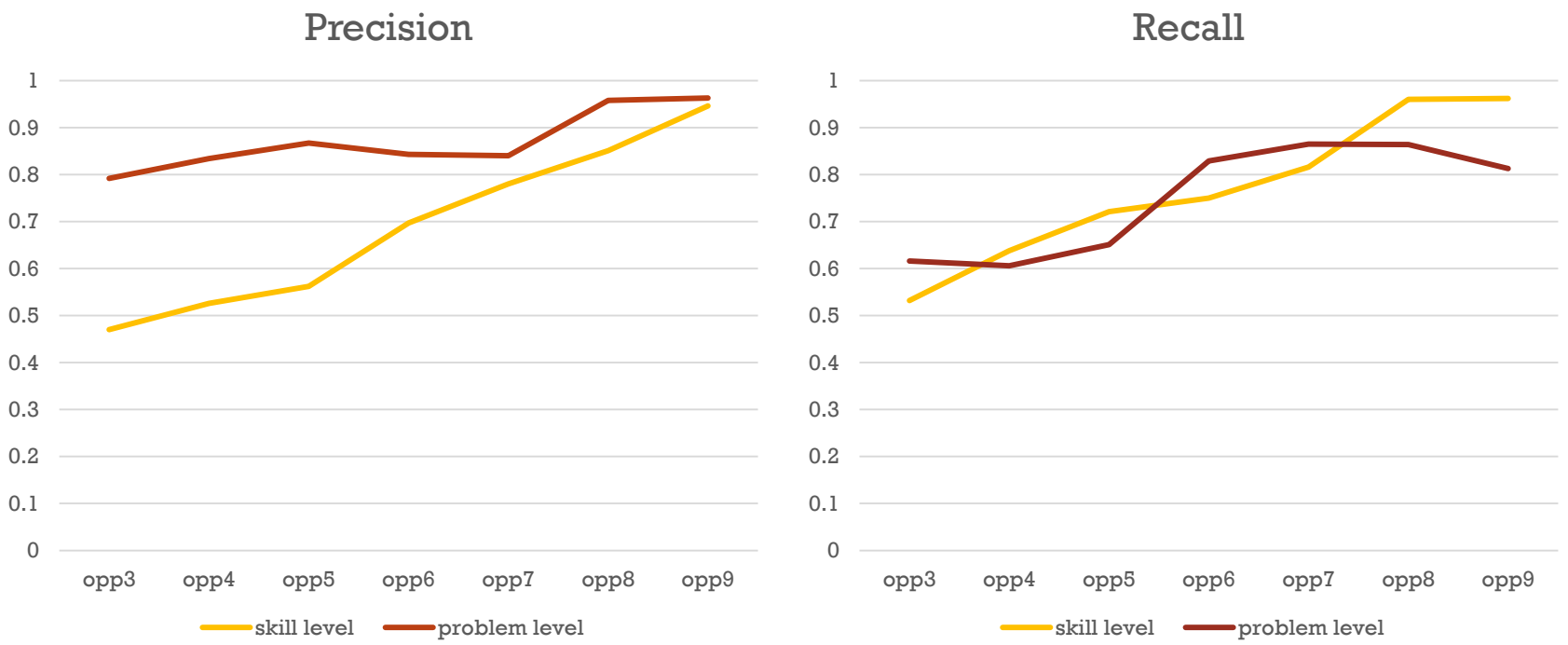
Prediction models & Results

Precision and Recall rate of two models



Prediction models & Results

Precision and Recall rate of the upgraded models
Skill level vs Problem level



GIFT Implication

- Predict students' unproductive failure (wheel spinning) on an ITS embedded into adaptive online courseware.
- Build the wheel-spinning predictor at the different level of granularity of the skill model
- Explore other machine learning techniques to improve the accuracy and speed of wheel-spinning prediction.

Future research

- What would be an effective intervention for those who are predicted to wheel spin on a problem?
- Explore other machine learning techniques to improve the wheel-spinning prediction model.
  - a drawback of using gradient boosted decision tree is that it is hard to interpret the model itself
- Extend the research regarding why students show unproductive failure in learning by using ITSs.

Thank you!

Any Question?