

# Evidence-based Method for Iterative Online Course Engineering with Students' Performance Profile

Noboru Matsuda and Machi Shimmei

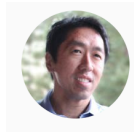
Department of Computer Science

North Carolina State University

# Key Learning Technologies

- **Massive Open Online Course**
- **Intelligent Tutoring Systems**

# Massive Open Online Course (MOOC)

- Self-contained, streamlined instruction
  - Evidence-based design (Clark & Mayer, 2003)
- Active learning
  - Multi-media, multi-modal, multi-activity (Collins, 2013)
- Potentially scalable
  - Machine Learning @ Stanford (Ng, 2011) **1.1M** 
  - Learning how to learn @ UCSD (Sejnowski & Oakley, 2014) **1.2M**



# Traditional MOOC

- Mostly, collection of videos

Matsuda & Shimmei

The screenshot shows a web browser window displaying a HarvardX CS50 course page. The URL is [courses.edx.org/courses/course-v1:HarvardX+CS50+X/courseware/bdc](https://courses.edx.org/courses/course-v1:HarvardX+CS50+X/courseware/bdc). The page header includes the edX logo, the course title "HarvardX: CS50 CS50's Introduction to Computer Science", and a user profile for "NoboruM". Navigation links include "Course", "Discussion", "FAQs", "Progress", "Status Page", "Syllabus", and "What's New for 2018". The breadcrumb trail is "Course > CS50x 2018 > Week 1 > Lecture". A video player interface is shown with a "Previous" button, a progress bar, and a "Next" button. The video title is "Lecture" with a "Bookmark this page" link. The video player shows a lecture with two men on a stage. The video player controls at the bottom indicate a duration of 0:00 / 1:26:36, a speed of 1.0x, and various playback controls. Below the video player, there are tabs for "Video" and "Transcripts".



# Traditional MOOC

- ... and some assessments.

courses.edx.org/courses/course-v1:TeachersCollegeX+BDE1x+2T2015/

TeachersCollegeX: BDE1x  
Big Data in Education

Help NoboruM

Course Discussion Wiki Progress Student Guide Course Reading List About Us Community

Week 3: Feature Engineering and Behavior Detection > Lectures > 3.4 Question

< Previous [icon] [icon] [icon] [icon] [icon] Next >

### 3.4 Question

[Bookmark this page](#)

### 3.4 Question

0 points possible (ungraded)

	G	H	I	J	K	L	Predicted
G		.7	.8	.8	.4	.3	.72
H			.8	.7	.6	.5	.38
I				.8	.3	.4	.82
J					.8	.1	.75
K						.5	.65
L							.42

Using Fast Correlation-Based Filtering. What variables will be kept? (Cutoff = 0.65)

☐ I, K, L

☐ I, K

☐ G, K, L

# MOOC: Challenges

- Lack of individualization
  - Ineffective learning (no learning!)
  - Disengagement / drop-out
- Lack of systematic content creation & validation
  - Where should we start from?
  - How can we iteratively make it better?

# Intelligent Tutoring Systems (Cognitive Tutors)

- Aimed mastery learning (Anderson et al. 1995)
  - Focus on a particular type of problem
- Macro- and micro-level adaptations (VanLehn 2006)
  - Adaptive problem sequence
    - Knowledge Tracing (Corbett & Anderson 1995a)
  - Immediate feedback and just-in-time hint
    - Model Tracing (Corbett & Anderson 1995b)

# ITS: Challenges

- Scalability / Generality
  - Too expensive to build
  - Mostly good for procedural skill acquisition
    - What about conceptual learning?
- Robustness of Learning
  - Lack of learning to solve with justifications

## Summary of Challenges

- To overcome the issues of MOOC and ITS, there is a critical need to innovate a technology that
  - provides **adaptive instruction** while promoting **synergetic learning**
- An **evidence-based curriculum development** is essential
  - to build a large scale online course

## Our Solution

- Evidence-based learning engineering methods
  - **PASTEL** (Pragmatic methods to develop Addaptive and Scalable Technologies for next generation E-Learning)
- Adaptive Online Courseware
  - **CyberBook**  
= MOOC + Intelligent Tutoring Systems + Adaptive Control

# CyberBook

- “Adaptive” online courseware
  - Problem sequencing
  - Just-in-time scaffolding
  - Mastery practice (aka cognitive tutoring)
  - Proactive detection of unproductive failure

# CyberBook: Example

Matsuda & Shimmei

kenya.education.tamu.edu:8000/courses/course-v1:University+CS101+2

University: CS101 Middle School Physics

Noboru

View this course as: Staff

[Home](#)
[Course](#)
[Discussion](#)
[Wiki](#)
[Instructor](#)

Bookmarks

Motion and Speed

Motion

Speed

Practice

Velocity and Acceleration

Forces with Anatomy

Friction

Newton's First Law

Newton's Second Law

Newton's Third Law of Motion

Epilogue

Motion and Speed > Motion > Motion


VIEW UNIT IN STUDIO

Bookmark

What is Motion?

As you sit at your desk, you can probably see many things in motion. The wind may be blowing tree limbs outside of the window, your classmate may be picking up a dropped pencil, or your teacher may be pacing as they teach. There are many ways to describe motion. These ways will be discussed in the following text.

Motion Defined



STAFF DEBUG INFO



# CyberBook: Adaptive Scaffolding

## Reading Checkpoint

According to Newton's Second Law: increasing force (1) \_\_\_\_\_ acceleration and increasing mass (2) \_\_\_\_\_ acceleration.

Answer for (1):

Answer:

✘ *Incorrect, please try it again.*



**Click this [link](#) to review the course content and examples on solving this question.**

Check

Hints


# Skill Name Association


Matsuda & Shimmei






University CS101  
Middle School Physics

Content ▾ Settings ▾ Tools ▾

Velocity and Acceleration / Velocity Defined






What is Velocity 

 Caution: The last published version of this unit is live. By publishing changes you will change the student experience.

Text **Skill Name: velocity**  EDIT    

## What is Velocity?

In reining horse competitions, riders receive a reining pattern so that they know what movements they must complete. Because of this, direction, as well as speed, is vital to their outcome. How can velocity help?

Reading Checkpoint **Skill Name: velocity**  EDIT    

### Reading Checkpoint

Velocity, as you previously read, is speed of an object in a given \_\_\_\_\_.

Answer:

Velocity is speed but adds for example: north, south, east or west. What are those?

Check

More Hints

# CyberBook: Cognitive Tutor Integration

The screenshot displays the CyberBook Cognitive Tutor interface. On the left is a navigation pane with a 'Bookmarks' tab and a search bar. The 'Line' category is expanded, showing sub-topics like 'Line basics-Definition of a line', 'Equation of a Line in Slope-Intercept Form', 'Equation of a Line in Standard Form', 'Y-intercepts', 'Slope', 'Find the Slope of Parallel Lines', and 'Find the Slope of Perpendicular Lines'. Other categories include 'Writing the Equation of a Line', 'Systems of Linear Equations', 'Right Triangles(0)', 'The Distance Between Two Points(0)', 'Area of a Triangle(0)', 'Squares', 'Distance From a Point to a Line(0)', 'Midpoints and Applications of Midpoint(0)', 'Circles(0)', and 'Ellipses'.

The main content area shows a breadcrumb trail 'Line > Slope > Unit'. Below this is a 'Bookmark' button. The problem title is 'Determine the slope of a line'. The problem text reads: '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'.

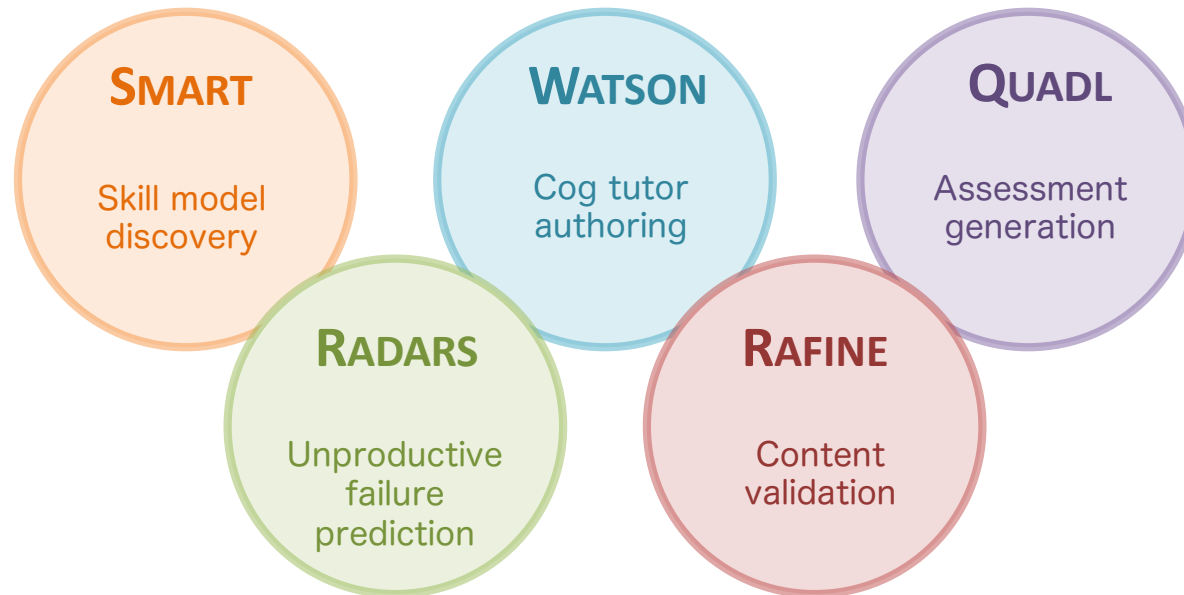
The equation is presented as:  $-x + y = 4$ . Below this, there are two sets of input fields for the slope-intercept form:  $y = \text{[ ]}x + \text{[ ]}$  and  $y = \text{[ ]}x + \text{[ ]}$ . The text 'so, slope is' is followed by an input field. A green 'Done' button with a checkmark is visible. At the bottom, there are navigation buttons: '<<', '>>', and a 'Hint' button.

# Technological Challenges

- Automatic validation of courseware content
- Rapid creation of a valid skill model
- Affordable authoring of cognitive tutors
- Automatic creation of formative assessments
- Reliable prediction of unproductive failure

# Technology Innovations

- PASTEL: Evidence-based, iterative learning engineering methods



### Technological Challenges

- Automatic validation of courseware content
- Rapid creation of high-quality skill-models
- Affordable creation of cognitive tutors
- Automatic creation of formative assessments
- Reliable prediction of unproductive failure

WATSON

Cog tutor  
authoring

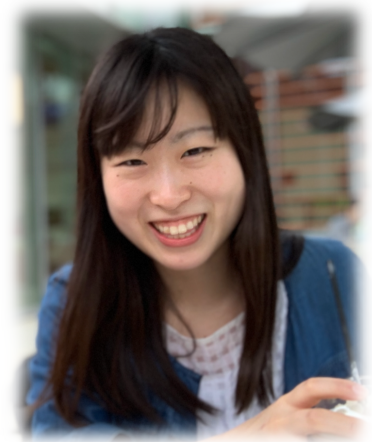
QUADL

Assessment  
generation

RAFINE

Content  
validation

Unproductive  
failure detection



## Problem: RAFINE

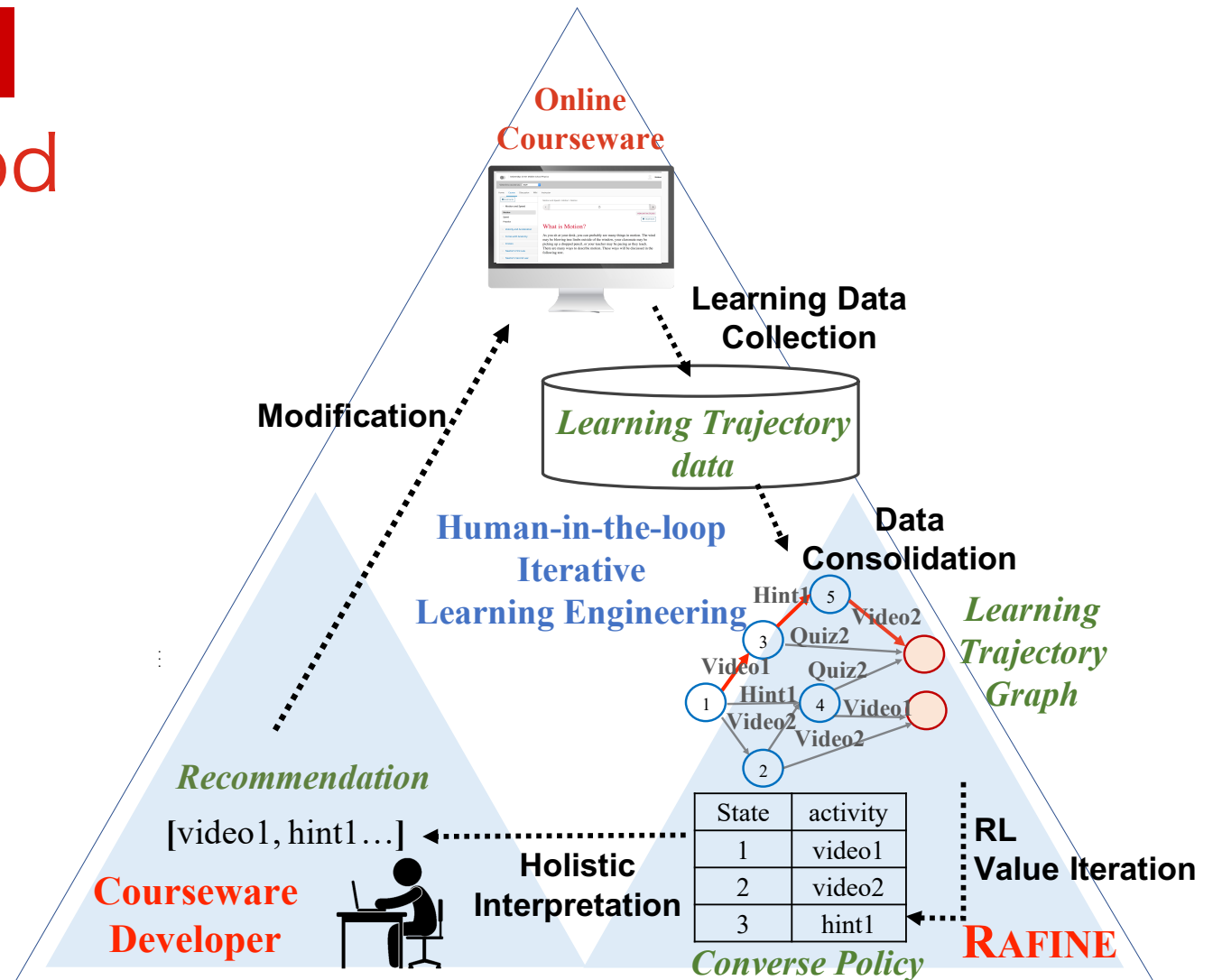
- Creating effective large-scale online course is very hard [Slavich & Zimbardo, 2012] [Clark & Mayer, 2003]
- Existing design theories still require iterative engineering [Fishman *et al.*, 2004]
  - Identifying issues with the courseware is one of the challenge.

## SOLUTION: RAFINE

- RAFINE (**R**einforcement learning **A**pplication **F**or **I**ncremental courseware **E**ngineering)
  - Automatically identifies relatively less effective instructional components on existing online courseware based on actual students' learning data



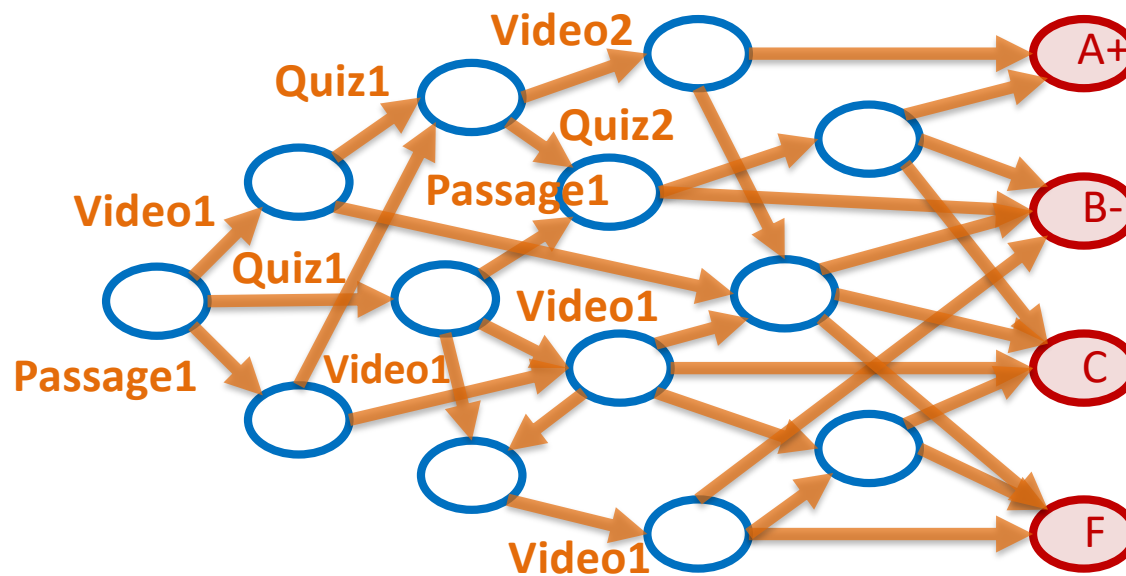
# RAFINE Method



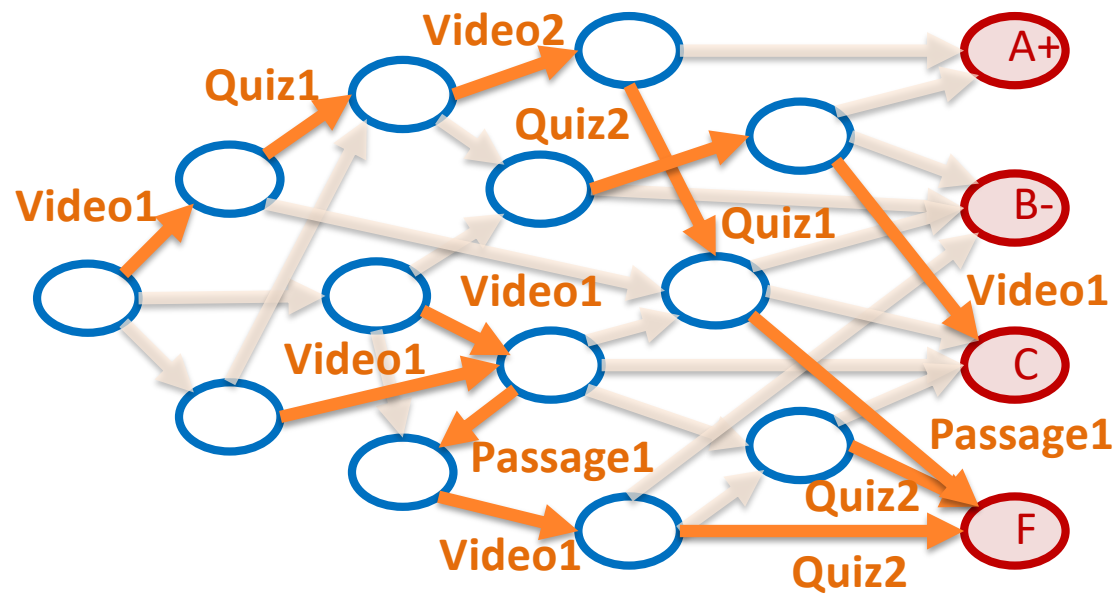
# Reinforcement Learning

- Given a **state transition graph (MDP)** with goals and a reward for each state,
- Compute a **policy** which shows optimal actions to be taken at a particular state
  - to maximize a likelihood of reaching to desired goals [Sutton *et al.*, 2018]

# Learning Trajectory Graph



# Converse Policy



# Atomic vs. Holistic Policy Interpretation

- Atomic interpretation of a policy
  - An optimal action at **each** state is predicted.
  - Tells which action should (or should not) be taken.
- Holistic interpretation of a policy
  - A collection of actions suggested as a policy over **all** states is analyzed.
  - Tells which actions are useful (or useless).

# Atomic vs. Holistic Interpretation

- Hypothesis:
  - By holistically analyzing a policy action set, relatively ineffective actions can be identified.
- In the current application...
  - A holistic interpretation of a policy action set induced from learning trajectory data will suggest the effectiveness of instructional components

# Converse Policy

- The action that minimizes the value function

$$\pi(s) = \operatorname{argmin}_{a \in A(s)} \underbrace{\sum_{s' \in S} T(s, a, s') (R(s, a, s') + \gamma V^\pi(s'))}_{\text{Value function } V(s)}$$

- The action that yields the least successful learning

# Reward

- $R(s, a, s') = \begin{cases} -0.14 & (ml(s) = ml(s') < 0.85) \\ -0.05 & (ml(s) < ml(s') < 0.85) \\ 0.95 & (0.85 \leq ml(s')) \end{cases}$
- $ml(s)$ : *masterly Level at state s*
- A reward at state  $s$  become the greatest when the successor state  $s'$  is a terminal state ( $ml(s') \geq 0.85$ )



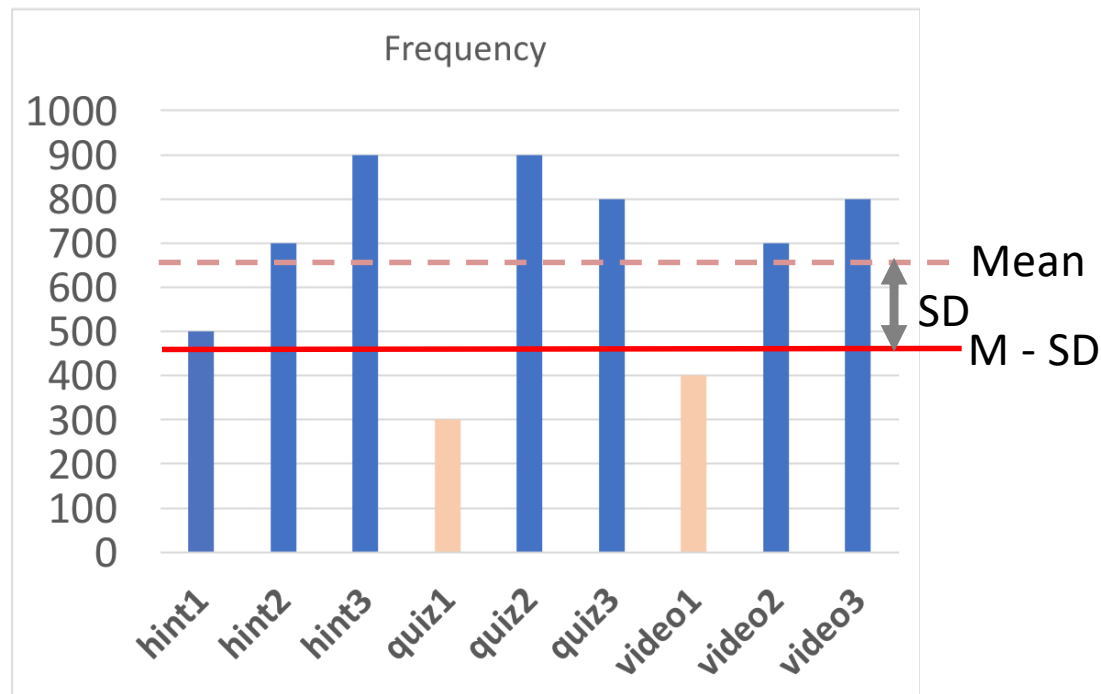
## Frequency Heuristic

- Relatively ineffective instructional components tend to appear in a converse policy action set more **frequently** than effective ones
- Instructional components that appear in a converse policy more than a pre-defined cut-off are included in a recommendation for refinement

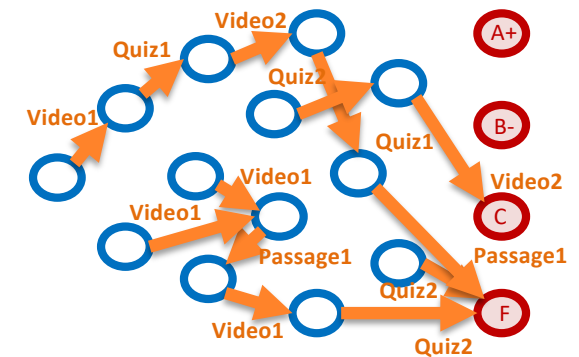
## Frequency Heuristic (Cont.)

- How frequent is “frequent”?
  - Mean freq. (M)  $\pm$  Standard deviation of freq. (SD)

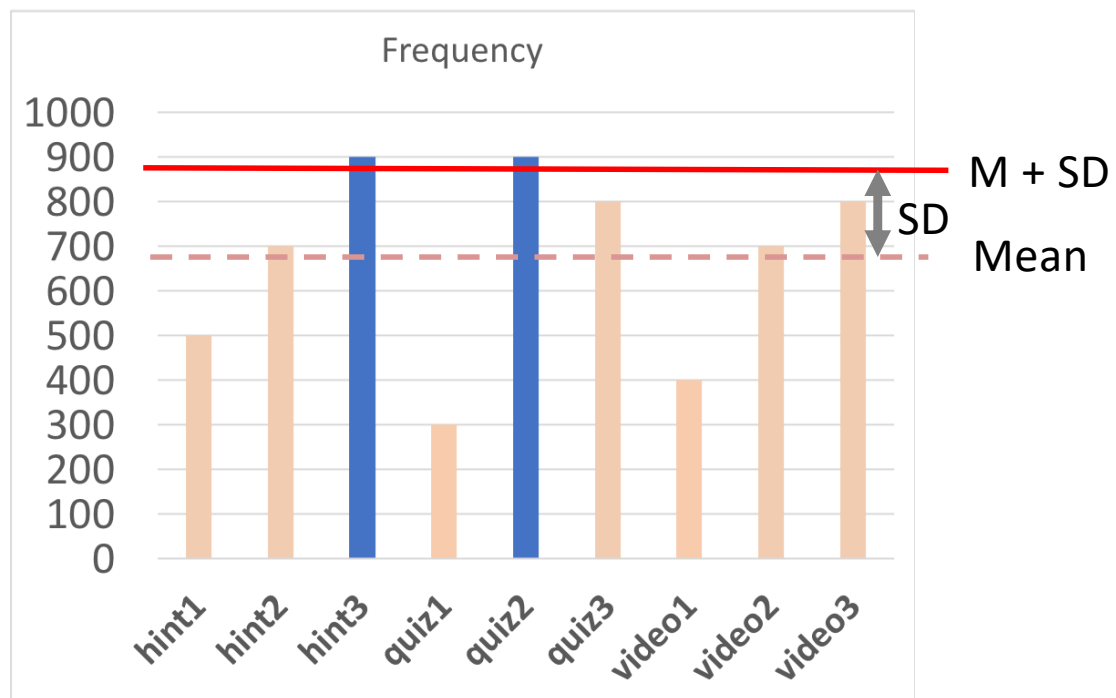
# Example: Frequency Heuristic (M-SD)



Ineffective  
Effective



# Example: Frequency Heuristic (M+SD)



# Research Questions

1. Can a converse policy correctly differentiate ineffective instructional components from effective ones?
2. How robust is the converse policy to detect relatively ineffective instructional components against different conditions of learning data?
3. How accurately does the frequency heuristic compose a recommendation?

## Simulation Study: Method

- To apply RAFINE, each instructional component is needed to be tagged with a skill
  - No such online courseware is currently available
- As a proof of concept, hypothetical students' learning trajectories on **mock online courseware** were used
  - Justifies future efforts

## Simulation Study: Method

- Mock online courseware
  - 9 videos, 9 quizzes with 9 hints in total
    - coded as either effective or ineffective
  - Masterly level (ML) increased at each commitment to an instructional component
    - Effective instructional compo. increases ML more than ineffective ones

# Simulation Study: Data

- **Quality** of courseware (effective : ineffective)
  - **High** (8:1), **Med** (4:5), **Low** (1:8)
- **Contrast** in the impact of taking an effective vs. ineffective instructional compo. on mastery level
  - **Large**, **Moderate**, **Small**
- In total 9 learning scenarios
  - Quality (**High**, **Med**, **Low**)  $\times$  Contrast (**L**, **M**, **S**)



## Simulation Study: Data (Cont.)

- For each scenarios, 100 instances of course offerings were simulated each with 1,000 simulated students
  - 1 Learning trajectory Graph (LTG) consists of 1,000 students data.
- Converse policy was computed for each LTG from each 9 learning scenarios
  - 100 converse policies for each scenarios
  - Total 900 converse policies == 900 recommendations

## Converse policy as a quality indicator

- Compare the frequency of individual component in policy action set
- Normalized Frequency (NF) of instructional compo. for skill  $\theta$

$$- \frac{|S^\pi(\theta)|}{|S^A(\theta)|} = \frac{\text{Num. of states in the LTG where } \theta \text{ is the policy action}}{\text{Num of states where } \theta \text{ was taken.}}$$

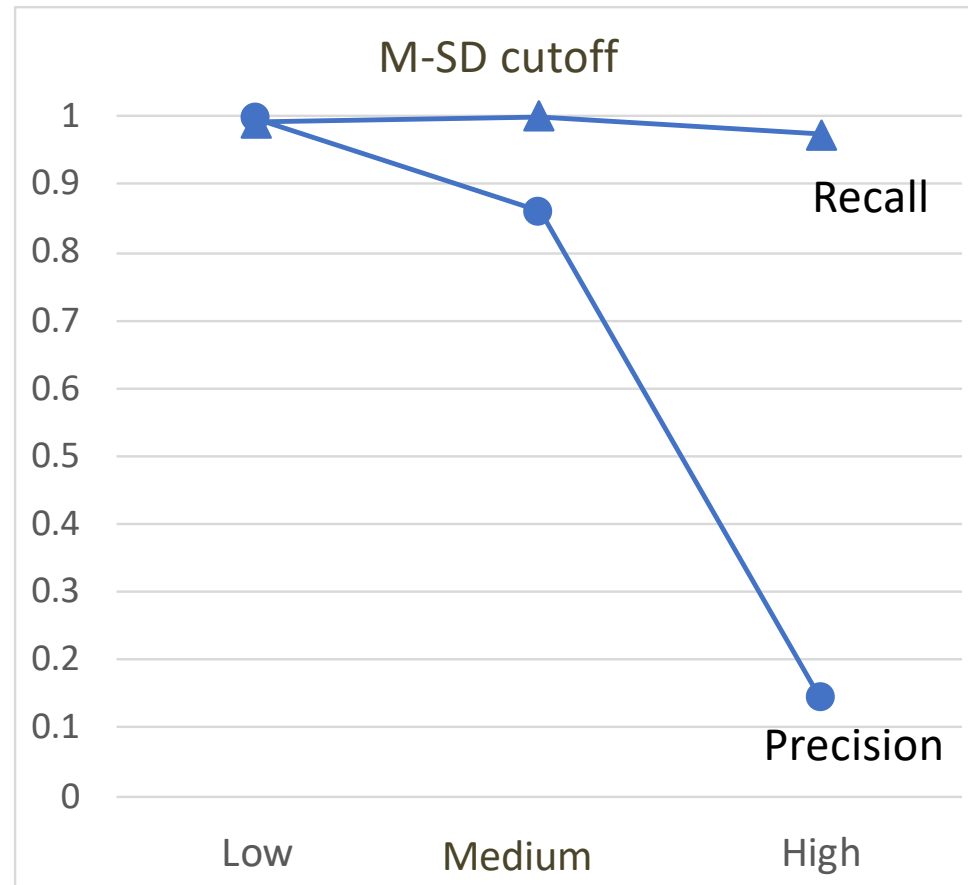
# Comparison of the mean NF (inef. vs. ef.)

	Contrast					
	Large		Moderate		Small	
Quality	Inef.	Ef.	Inef.	Ef.	Inef.	Ef.
High	0.7±0.2	0.2±0.1	0.7±0.1	0.1±0.1	0.5±0.1	0.2±0.1
	(effect size=4.0)		(5.7)		(3.1)	
Med.	0.4±0.1	0.1±0.05	0.4±0.1	0.1±0.04	0.4±0.1	0.2±0.1
	(7.9)		(8.5)		(3.6)	
Low	0.4±0.1	0.04±0.04	0.4±0.1	0.04±0.03	0.4±0.1	0.1±0.1
	(9.2)		(10.0)		(4.5)	

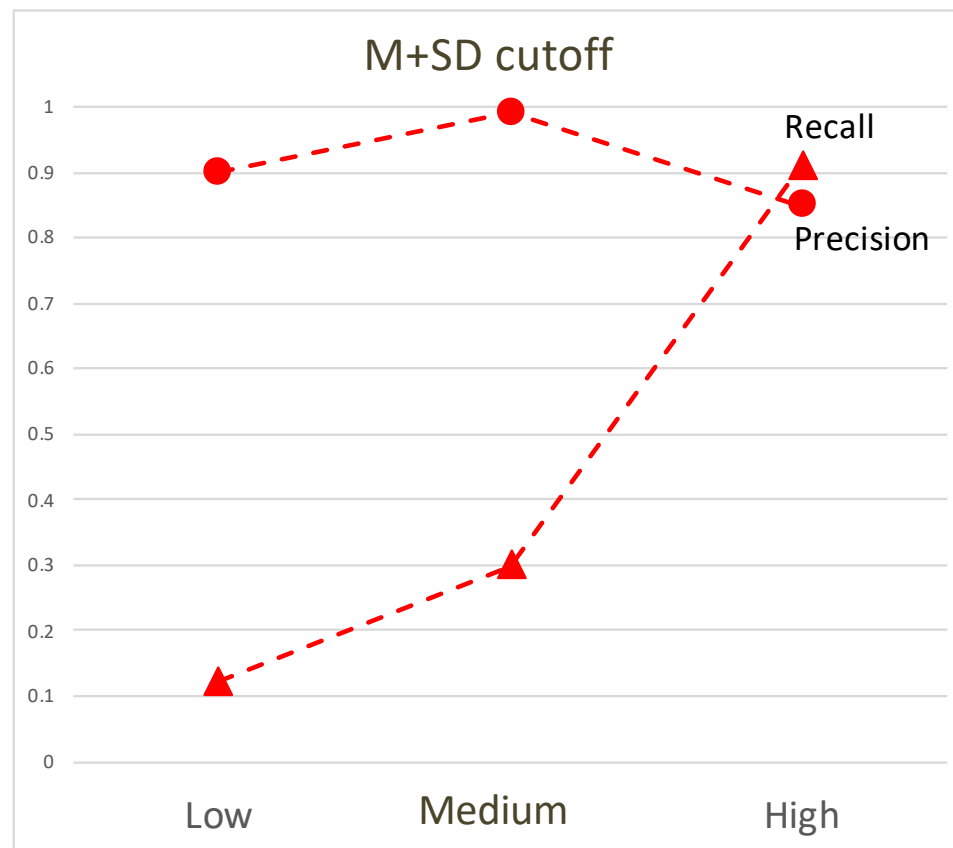
# Converse Policy as a Quality Indicator

- Frequency heuristic hypothesis was supported
  - **Ineffective** instructional components were selected more than **effective** as a converse policy
- Converse policy was robust enough to discriminate the effectiveness of the instructional component regardless of quality and contrast of online courseware

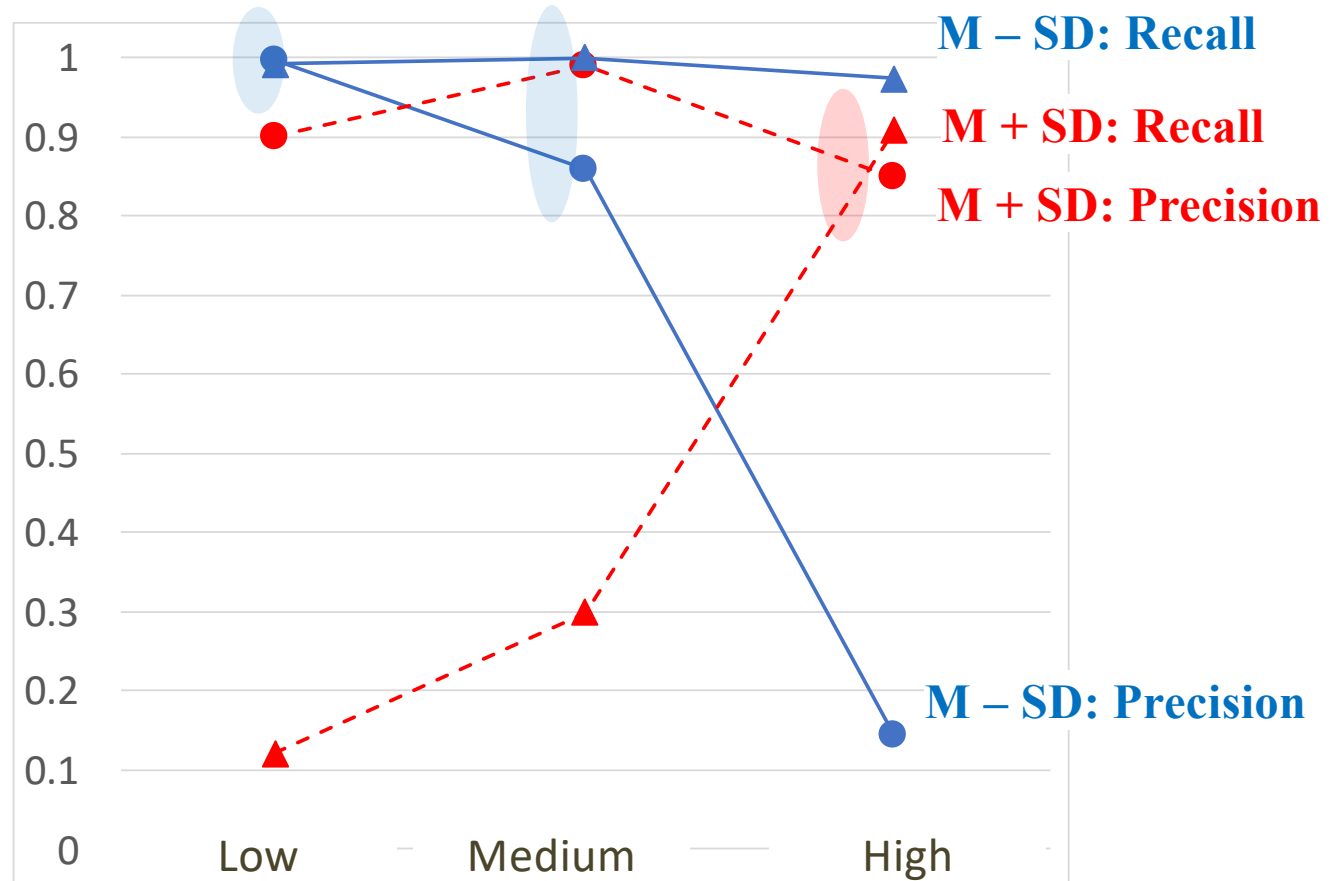
# Frequency Heuristic for recommendation



# Frequency Heuristic for recommendation



## Frequency Heuristic for Recommendation



# Frequency Heuristic for Recommendation

- Over 90% of ineffective instructional components were correctly taken as a recommendation when an appropriate cut-off was used based on the maturity of the courseware



## Conclusion (RAFINE)

- Holistic interpretation over a converse policy is a powerful analytic tool for the quality control
- Converse policy computed based on actual learning data will provide an insight into the usefulness of instructional component of online courseware

## Limitations and Future study

- How much students' individual differences affect the “effectiveness” of each instructional component
  - Assume that the majority vote applies
- Evaluate RAFINE method in authentic learning settings

## Conclusion (Self-Improving System)

- With RAFINE, we have half-built self-improving adaptive online courseware
- The remaining half is to let the machine automatically generate the content
  - Semi-automated creation of ITS
  - Question generation

# Thank you!