A Unified Framework for Knowledge Assessment and Progression Analysis and Design

Shuhan Wang        Fang He        Erik Andersen
Level 3
Level 2
Level 1
Student’s Knowledge
Current Education System

Educator

Python

Python!

Content

Classroom

Feedback

Separate
Our Unified Framework

**Framework**

- A
- B
- AB
- ABC
- ABCB
- BCC
- AABC
- ABCBD
- D

**Knowledge Assessment**

**Performance Prediction**

**Learning Progression Analysis**
Our Unified Framework

- Framework
- Knowledge Assessment
- Performance Prediction
- Learning Progression Analysis
Knowledge Organization

Study the relationship between practice problems & Build the hierarchical structure.
Partial Ordering on Practice Problems

\[ p_1 \text{ is at least as hard as } p_2 \text{ if:} \]

\[ \text{skills}(p_1) \supseteq \text{skills}(p_2) \]
Practice Problems

A

B

AB

BCC

AABC

ABCB

D

ABCBD
Partial Ordering Graph
Property of Partial Ordering

If $p_2$ is at least as hard as $p_1$, then

• Students who understand $p_2$ will also understand $p_1$
• Students who don’t understand $p_1$ will not understand $p_2$
Coloring Partial Ordering Graph
Coloring Partial Ordering Graph
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Knowledge Boundary
Knowledge Boundary

Knowledge Boundary (K.B.):

the set of the hardest problems that a student can understand.

We use Knowledge Boundary to model a student’s knowledge within the Partial Ordering Graph.
Our Unified Framework

- Knowledge Assessment
- Performance Prediction
- Learning Progression Analysis
Rasch Model

Student Performance $P$ is a function of the difference between the student’s ability $\theta$ and the problem’s difficulty $b$.

$$P(\theta, b) = \frac{e^{\theta - b}}{1 + e^{\theta - b}}$$

<table>
<thead>
<tr>
<th></th>
<th>Student Ability $\theta$</th>
<th>Problem Difficulty $b$</th>
</tr>
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<tr>
<td>Rasch Model</td>
<td>Unidimensional Numeric Scores</td>
<td></td>
</tr>
<tr>
<td>Our Model</td>
<td>Knowledge Boundary</td>
<td>Node in Partial Ordering Graph</td>
</tr>
</tbody>
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Distance to Knowledge Boundary

In order to measure the **difference** between student ability $\theta$ and problem difficulty $b$,

We calculate the **distance** between Knowledge Boundary and the problem(node) in Partial Ordering Graph.
Experiments: A Japanese Assessment Tool

First 10 sentences:

• Students answered whether they can understand those sentences.
• The responses were used for assessing students’ knowledge.

Next 5-8 sentences:

• Students answered how well they understand those sentences.
• The responses were used as the test set for performance prediction.
Results
Our Unified Framework

Framework

A
B
AB
BCC
AABC
ABCB
D
ABCBD

Knowledge Assessment

Performance Prediction

Learning Progression Analysis

- Genki
- Reinforcement
- Recombination
- Introduction

Standard Japanese
When I have a “Library” of practice problems

Which Problem should I learn first?

This is too hard!! Am I learning too fast?

When should I review what I have learned?

Learning Progression
In order to automatically design learning progressions, we need to study expert-designed learning progressions.
Progression Analysis on Textbooks

We are Looking for General Principles of designing good learning progressions.
Progression Metric: Learning Pace

A student’s *Knowledge Size* is the number of problems $p$ s.t. the student has learned $p$ or some other problem that is harder than $p$.

$$Pace = \frac{\Delta \text{Knowledge Size}}{\Delta \text{time}}$$

Both textbook progressions are following a similar, steady pace.
Progression Metric: Balance of Learning and Review

We classify problems in a learning progression into **Introduction**, **Reinforcement** and **Recombination**.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Knowledge</th>
<th>Classification</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>Introduction</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>Introduction</td>
</tr>
<tr>
<td>3</td>
<td>BC</td>
<td>Introduction</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>Reinforcement</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>Reinforcement</td>
</tr>
<tr>
<td>6</td>
<td>ABC</td>
<td>Recombination</td>
</tr>
</tbody>
</table>
Progression Metric: Balance of Learning and Review
Future work

• Apply to Different Educational Domains
  • Especially Computer-Assisted Language Learning (CALL)

• A Science of Progression Analysis
  • Pacing and Sequencing: Find the Best Principles.

• Automatic and Adaptive Tutoring System
  • Rapid Initial Assessment
  • Progression Tailoring
Summary

• Organizing Practice Problems into **Partial Ordering Graph**
  • A hierarchical structure of knowledge

• Knowledge Assessment within Partial Ordering Graph
  • Knowledge Boundary -- student modeling
  • Distance to K.B. -- performance prediction

• Analyzing Learning Progressions from Textbooks
  • Learning pace
  • Balance of Learning and Review