Bridge the Gap between Educators and Students in Online Learning: A Visualization Approach based on Problem-solving Data

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Co-supervised by Prof. Huamin Qu and Prof. Xiaojuan Ma
Outline

1. Background

2. Visual Analytics for Educators
   2.1 *QLens* for Question Designs (Micro Level)
   2.2 *SeqDynamics* for Evaluating Students (Macro Level)

3. Information visualizations for Students
   3.1 *Game the system* for Learning behavior regulation (Micro Level)
   3.2 *PeerLens* for Learning Path Planning (Macro Level)

4. Conclusion & Future Directions
Online Learning is Important

• 94/98 countries closed the schools in March and most of them encouraged online learning at home (Organization for Economic Co-operation and Development, 2020)

• It is an irresistible trend that “learning centre” will replace the “school” in the future

A Framework to Guide and Education Response to the COVID-19 Pandemic by OECD (Organization for Economic Co-operation and Development) and the Harvard School of Graduate Education.
## Online Learning Types

<table>
<thead>
<tr>
<th>Type</th>
<th>Online learning platforms</th>
<th>Examples</th>
<th>Learning Materials</th>
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<tbody>
<tr>
<td>Video-based</td>
<td>Learning Management System</td>
<td>Canvas, Moodle, Coursera, EdX, Udacity</td>
<td>Video/lectures</td>
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<td>Question-based</td>
<td>Intelligent tutoring system</td>
<td>Algebra Tutor, SmartTutor</td>
<td>Problems</td>
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<td>Test and quiz systems</td>
<td>LeetCode, Uva</td>
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<tr>
<td></td>
<td>Learning Objects repositories, wikis, forums, educational games, Q/A systems</td>
<td>StackOverflow</td>
<td>Questions</td>
</tr>
</tbody>
</table>
Question-based Learning Platforms

• Become popular increasingly
• Practice **problem-solving skills**

*(Vanlehn Kurt., 2006)*
Problem-solving skills

• Cognitive perspective: ability to engage in cognitive processing to understand and solve problem situations where a method to solve the problem is not immediately available

• Non-cognitive perspective: motivation to engage with such situations in order to “achieve one’s potential as a constructive and reflective citizen” (Organization for Economic Co-operation and Development, 2014)

• Problem-solving skills is one important competency that should be fully embraced in the education systems (Shute et al., 2016)
Problem-solving processes

Micro level: students’ behaviors within a question (Vanlehn Kurt, 2016)

Macro level: students’ behaviors among questions (Vanlehn Kurt, 2016)
Challenges

• Imbalance in the number of educators and students
• Huge amount of learning resources, i.e., questions

...
Motivation

Empower educators: analyze students’ problems-solving processes
• Improve the question designs
• Give customized instructions

Empower students: improve learning, becoming “educators”
• Self-regulate their learning habits
• Plan the personalized learning paths

(Koedinger et al, 2015)
A visualization approach

• Educators need to explore the patterns based on the real data
• Students need to reflect and plan learning according to their motivations

Automatic algorithm ✗ Keep educator and students in the loop ✓

Data Mining + Visualization → Visual Analytics

- Clearly defined tasks
- Automated process
- Objective results
- High-bandwidth channel
- External perceptual system
- Interaction
- Exploratory analysis
- Involve human knowledge
- Deeper understanding
Related Work

Problem-solving Behavior Modelling

Macro level (a series of problems):

• Liu, R., & Koedinger, K. (2017). Going beyond better data prediction to create explanatory models of educational data. The Handbook of Learning Analytics, 69-76.


Micro level (one multi-step question):


Not comprehensive (cognitive & non-cognitive); not well interpreted.
Related Work

Learning Sequence Visualization (video clickstream/assignments):


Problem-solving sequences are more detailed and complex, which include the feedback on each step/question.
Our works

**Qlens**: multi-step question analysis. VIS 2020 (conditionally accepted)

**SeqDynamics**: problem-solving dynamics analysis. Euro VIS, 2020

**Peerlens**: learning path planning. CHI, 2019

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“Our works”:

- **“Game the system”: learning behavior regulation. L@S, 2020**

Empower educators

Problem-solving Data

Empower students

Micro level

Macro level
Our works

**Qlens**: multi-step question analysis. VIS 2020 (conditionally accepted)

**SeqDynamics**: problem-solving dynamics analysis. Euro VIS, 2020

**Peerlens**: learning path planning. CHI, 2019

**“Game the system”: learning behavior regulation. L@S, 2020**
QLens: Visual Analytics of Multi-step Problem-solving Behaviors for Improving Question Design

Meng Xia, Reshika Palaniyappan Velumani, Panpan Xu, Yong Wang, Huamin Qu, Xiaojuan Ma

IEEE VIS 2020 (Conditionally accepted)
A Multi-step Question

Five people stand in a line.

Mark stands ahead of Paul.
Helen stands ahead of Jane.
Paul stands behind Helen but ahead of Luke.
No boy is next to another boy in the line.

Move each person to their place in the line.
Motivation

- Problem-solving logic
- Engagement level
- Difficulties

Question Designer
Related work

- States cannot reflect students’ thinking logic
- Difficult to support analytical tasks, e.g., comparison

(Liu et al., 2011)

(Wang et al., 2017)

(Xia et al., 2019)
QLens for question designers

Inspect

Analyze

Compare
A user-centered design process

• Four domain experts
  • Question designers (E1, E2)
  • System developer (E3)
  • Project manager (E4)

• Requirements gathering iteratively >= one year

  R1: Show students’ overall problem-solving performance.
  R2: Summarize and present the multi-step problem-solving behaviors.
  R3: Enable the comparison of students from different groups.
  R4: Evaluate the feasibility of providing feedback based on existing data.
System overview
1. Data Preprocessing

April 2019 to January 2020, 2,306,644 records from 5,266 students and 1,718 mathematical questions.

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<tr>
<td>Browser</td>
<td>Chrome/IE/Safari</td>
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</table>
1. Data Preprocessing

For each question:

Five people stand in a line.
Mark stands ahead of Paul.
Helen stands ahead of Jane.
Paul stands behind Helen but ahead of Luke.
No boy is next to another boy in the line.
Move each person to their place in the line.

For each student:

2 11 4 7 3 8 8 9 ...

Step1: ,,,,Mark
Step2: Paul,,,,Mark
Step3: Paul,Helen,,,,Mark
Step4: Paul,,Helen,,Mark
...

2. Data Analysis - State Transition Model

**Step:** the smallest user interface interaction that changes the intermediate answers

**Stage:** the number of conditions the current answer fulfills

**Condition:** one criteria that students need to fulfill to get the partial score

<table>
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<tr>
<th>Condition</th>
<th>Score</th>
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<tr>
<td>Mark &gt; Paul</td>
<td>149/233</td>
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<tr>
<td>Helen &gt; Jane</td>
<td>140/233</td>
</tr>
<tr>
<td>Luke &gt; Paul &gt; Helen</td>
<td>78/233</td>
</tr>
<tr>
<td>No boys near each other</td>
<td>0/233</td>
</tr>
</tbody>
</table>

Step 1: „„„,Mark  
Step 2: Paul„„„,Mark  
Step 3: Paul,Helen„„„,Mark  
Step 4: Paul„„„,Helen„„„,Mark  
...
3. Visualization - State Transition Visualization

State:

Level1: \{Step, Stage\} + \{Condition array, Time elapse, Trajectory length\}

Level2: \{Intermediate answer\}
3. Visualization - State Transition Visualization

State:

Level1: \{\text{Step, Stage}\} + \{\text{Condition array, Time elapse, Trajectory length}\}

Level2: \{\text{Intermediate answer}\}
3. Visualization - State Transition Visualization

State:

Level 1: \{\text{Step, Stage}\} + \{\text{Condition array, Time elapsed, Trajectory length}\}

Level 2: \{\text{Intermediate answer}\}
3. Visualization - State Transition Visualization

State:

Level1: {Step, Stage} + {Condition array, Time elapse, Trajectory length}

Level2: {Intermediate answer}
3. Visualization - State Transition Visualization

State:

Level1: \{\text{Step, Stage}\} + \{\text{Condition array, Time elapse, Trajectory length}\}

Level2: \{\text{Intermediate answer}\}
3. Visualization - State Transition Visualization

State:

Level 1: \{\text{Step, Stage}\} + \{\text{Condition array, Time elapse, Trajectory length}\}

Level 2: \{\text{Intermediate answer}\}
Case study: Check the Gap between Design Intention and Problem-solving Behavior
Five people stand in a line.

Mark stands ahead of Paul.
Helen stands ahead of Jane.
Paul stands behind Helen but ahead of Luke.
No boy is next to another boy in the line.

Move each person to their place in the line.
Consider the condition with the most restrictions: “No boy is next to another boy in the line.”

There are only 3 boys and 2 girls, so we have

```
Back    Boy  Girl  Boy  Girl  Boy  Front
```

“Mark stands ahead of Paul”, “Paul stands ahead of Luke”. Therefore,

```
Back    Luke  Girl  Paul  Girl  Mark  Front
```

“Helen stands ahead of Jane”. Therefore,

```
Back    Luke  Jane  Paul  Helen  Mark  Front
```
Evaluation

- **Cases studies** with four domain experts during the development
- **Semi-structured interviews** with another three domain experts (two questions designers form a different education company, one senior manager); each interview lasts about 1.5 hours

1. Introduce system
2. Introduce three cases
3. Free exploration
4. Answer questions
Evaluation

System usefulness

Overall, all experts confirmed the **usefulness** and the **intuitiveness** of the system.

“The insights from Transition View will be very useful for the question designer (for example to decide which question is more suitable for which grade students) and the system developer.”

--- E6

“As more and more learning activities conducted are online, it was also very useful to compare students from different schools (e.g., international and local ones) or regions.”

--- E5

“The on-the-fly guidance is what we expected but needs more considerations.”

--- E5

Visual design & interactions

“It is so clear to view the problem-solving process using the visualization like this (Transition View).”

--- E7
Conclusion

• An interactive visual analytics system on multi-step question design

• A novel glyph-embedded Sankey diagram

• Three case studies and interviews with domain experts

How can we analyze students’ behaviors on macro level (multiple questions)?
Our works

- **Qlens**: multi-step question analysis. VIS 2020 (conditionally accepted)
- **SeqDynamics**: problem-solving dynamics analysis. Euro VIS, 2020
- **“Game the system”**: learning behavior regulation. L@S, 2020
- **Peerlens**: learning path planning. CHI, 2019

Empower educators ↔ Problem-solving Data ↔ Empower students

Micro level ↔ Macro level
SeqDynamics: Visual Analytics for Evaluating Online Problem-solving Dynamics

Meng Xia, Min Xu, Chuan-en Lin, Ta Ying Cheng, Huamin Qu, Xiaojuan Ma

EuroVIS 2020
Elite Selection in University

Interview in IT Company

FAIL

OR

PASS
Elite Selection in University

Interview in IT Company

Cognitive skills (think, read, learn, remember, reason, and pay attention)

Noncognitive traits (motivation, conscientiousness, perseverance, self-regulation, and collaboration)
Cognitive skills (think, read, learn, remember, reason, and pay attention)

Noncognitive traits (motivation, conscientiousness, perseverance, self-regulation, and collaboration)

Elite Selection in University

Interview in IT Company

Exams/Technical interviews

Performance and behavior on a long period.
<table>
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Problem-solving Dynamics

The process and progress of solving a series of problems over time.

<table>
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<tr>
<th>Problem ID</th>
<th>Results</th>
<th>Difficulty</th>
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<td>Easy</td>
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<tr>
<td>2</td>
<td>🟥</td>
<td>Medium</td>
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<td>5</td>
<td>☢️</td>
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<tr>
<td>8</td>
<td>☢️</td>
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<tr>
<td>13</td>
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<th>Problem ID</th>
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<td>2</td>
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<td>Hard</td>
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Cognitive Skills

e.g., learning curve
Problem-solving Dynamics

The process and progress of solving a series of problems over time.

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<td>Medium</td>
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<td>8</td>
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<td>Easy</td>
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<tr>
<td>21</td>
<td>![Green Circle]</td>
<td>Medium</td>
<td>Jan. 20</td>
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Non-cognitive Trait

e.g., self-regulation

![Calendar Image]
SeqDynamics

Interactive

Multi-dimensional

Time-series
A user-centered design process

Four domain experts

- Recruiters from the competitive programming team (E1, E2)
- Student coaches (E3, E4)

Requirements gathering iteratively for three months

R1: Show a clear overview of overall students’ problem-solving performance.

R2: Understand problem-solving dynamics from different perspectives over time. (i.e., cognitive and non-cognitive).

R3: Compare/Combine the problem-solving performance at different scales.

R4: Support an interactive and customized exploration of the evaluation.
System overview
Problem-solving Feature Extraction

Changes of these features below over time:

Cognitive ability (Ausubel et al., 1968)
• L1: number of problems solved
• L2: ratio of hard problems solved
• L3: diversity of problems solved

Non-cognitive traits (Farkas, 2003)
• L4: number of submissions (diligence level)
• L5: time starting to trying hard problems (willingness to take challenge)
• L6: ratio of active days (perseverance)
User Interface
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<th>ELO Rank</th>
<th>Customized Rank</th>
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<tr>
<td>NO15 Score894</td>
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<tr>
<td>NO16 Score892</td>
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<tr>
<td>NO17 Score887</td>
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<tr>
<td>NO18 Score875</td>
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<tr>
<td>NO19 Score864</td>
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<tr>
<td>NO20 Score859</td>
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<tr>
<td>NO21 Score858</td>
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<td>NO22 Score852</td>
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<td>NO23 Score846</td>
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<td>NO24 Score834</td>
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<td>NO25 Score833</td>
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<td>NO26 Score827</td>
<td></td>
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<tr>
<td>NO27 Score809</td>
<td></td>
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</tr>
</tbody>
</table>
Case 1: Elite Analysis and Selection
Evaluation

Three usage scenarios
Elite Analysis and Selection
Personal Analysis and Training
Team Formation

Five expert interviews
(Three coaches of competitive programming teams and two instructors teaching programming courses)

- System Usability
- System Effectiveness
- Visual Designs
- Interactions

“The encoding (glyph) is very intuitive and I can tell a learner’s talent at a glance”

“The hexagon can clearly show the strength and weakness of two candidates”

Overall, all five experts commented that SeqDynamics was useful and easy to use.
Conclusion

• An interactive visual analytical system

• Novel glyphs and bilateral stacked graph

• Three usage scenarios and five expert interviews

How can students make use of peers’ problem-solving data?
Our works

Qlens: multi-step question analysis. VIS 2020 (conditionally accepted)

SeqDynamics: problem-solving dynamics analysis. Euro VIS, 2020

“Game the system”: learning behavior regulation. L@S, 2020

Empower educators

Problem-solving Data

Empower students

Micro level

Macro level

Peerlens: learning path planning. CHI, 2019

Empower educators

Empower students
Using Information Visualization to Promote Students’ Reflection on “Gaming the System” in Online Learning

Meng Xia, Yuya Asano, Joseph Jay Williams, Huamin Qu, Xiaojuan Ma

L@S 2020
“Gaming the system”

Students exploit properties and regularities of the learning system, rather than learning the material (Ryan Baker et al., 2004).

- **Quickly and repeatedly asking for help** until the correct answer is provided
- **Quickly and systematically guessing the answers** until correct (Ryan Baker et al., 2008)
Universality and consequences

10-40% of students showed any forms of gaming behavior in MOOCs (Northcutt et al., 2016).

Students who game the system tend to have reduced learning gains and lower long-term academic achievements (Joseph Beck and Ma Mercedes T Rodrigo, 2014).
Related Work

- Added constraints, e.g., introduced a two-second delay between each level of a multi-level hint (Aleven et al., 2001; Joseph et al., 2005)

- Developed techniques on detecting gaming behavior using machine learning or feature engineering (Pardos et al., 2014). Applied interventions only when students were detected as having gaming behavior, e.g., imposing more exercises to gaming students
Research gap

• If tweaks fail to promote people’s reflection on why behavior change is necessary, their effects may fade away quickly once removed (Caraban et al., 2019)

• Dual-process of decision-making (Daniel Kahneman, 2011)
  
  Automatic (little effort, emotional, and unconscious)
  Reflective (effortful, rational, and conscious)

It is critical to design reflective mechanisms that can promote students’ reflection on gaming behavior.
Proposed solution

• The persuasiveness of data visualization has been revealed in a wide range of recent research (Pierre Dragicevic and Yvonne Jansen, 2017; Pandey et al., 2014; Agapie et al., 2013; Turland et al., 2015)
  • Estimate drug efficacy
  • Change the attitude toward political topics

Reflective nudge = reasoning information + persuasive visualization
Research questions

RQ1: What are the typical contexts in which students may try to game the system and what are the possible negative consequences on learning when gaming occurs in these contexts?

RQ2: What are the ways to encode information for communicating reasons not to game in various contexts into reflective nudge to students?

RQ3: What are the design considerations for creating reflective nudge to promote reflection in online learning?
RQ1: Contexts of gaming and its negative consequences on learning

Method: semi-structured interviews

- Students’ perspectives: 16 students (12 males, age: 23±3.38):
  1) How often do you indulge in gaming behavior, if at all?
  2) Under what circumstances are you likely to game the system and why?

- Instructors’ perspectives: three instructors including one system developer:
  1) What are the intentions behind the initial design of the system?
  2) What’s your observed students’ practice on the system?
  3) What are your attitudes toward certain practices?
  4) What are the suggestions and potential solutions?
Results of RQ1

Students:

<table>
<thead>
<tr>
<th>Contexts of gaming the system</th>
<th># of interviewees (out of 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1: When students are busy, they may game to save time on this course.</td>
<td>10</td>
</tr>
<tr>
<td>C2: When faced with difficult problems, they feel frustrated and game to keep up the pace.</td>
<td>8</td>
</tr>
<tr>
<td>C3: They think some concepts are unimportant, thus game quickly through.</td>
<td>3</td>
</tr>
<tr>
<td>C4: When the video is not clear, they do not want to spend time on exercises.</td>
<td>2</td>
</tr>
<tr>
<td>C5: When the deadline is at noon, they can not get up early in the morning.</td>
<td>2</td>
</tr>
</tbody>
</table>

Instructors:

R1: Randomly guessing answers with the intent to save time, which would cost students’ much more time in the review period.

R2: Gaming in the face of difficult problems assuming it is the only way to keep up with their peers, but difficult problems also take other students' considerable effort to solve.

R3: Gaming problems related to seemingly unimportant concepts, but the negligence of those concepts may hinder the mastery of later concepts depending on them.
RQ2: Encoding reasons not to game into reflective nudges

Method: iterative design

• Collect the submissions on **multiple-choice questions**
• Initial ideation and **prototyping** phase: 10+ low-fidelity (sketch)
• **Participatory interviews** with two instructors to get feedback on each visualization, narrowing down to three designs
• **Informal testing** with seven students (two females, five males, age: 24±2.85) to improve the visual designs
Information Visualization V1: Time on problem

Here is how people spend their time on this problem:

**Good students:** more reflection time + less review time:

```
... >=20(s)  >=20(s)  >=20(s)  ...
```

- Latest submission
- Exam

**Struggling students:** less reflection time + more review time:

```
... ... ...
```

- Latest submission
- Exam

**Your recent submission records:**

```
...
```

- Latest submission
- Exam
Information Visualization V2: Number of attempts

Here is your attempts history:

- Mean attempts: 4
- Submission sequence: All attempts are shown in the bar chart.
- Historical first-time pass rate: 0.16
- You beat 70% students
- You tried: 4 times

The chart illustrates the number of attempts made by the student and compares the results to the historical pass rate.
Here are the prerequisite concepts of the current problem (click the rectangle):

- Type String
- Defining Functions
- Input/output & String Formatting
- Integer, String & Float Conversion
- More String Operations

A → B: A is the prerequisite of B

- Mastered
- Need to review
- Current module
- Future module
RQ3: Design consideration for reflective nudge in online learning

**Method:** We evaluated our information visualizations (V1 - V3) through:

- Deployment on a university-level introductory programming course with 205 students
- Three experimental (V1-V3) groups and one control group
- Questionnaire after students received interventions
- Post-study interviews to gather reasons behind their questionnaire ratings and suggestions
## Results of R3 - Potential gaming reduction

<table>
<thead>
<tr>
<th></th>
<th>Without intervention</th>
<th>With intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P1</td>
<td>P2</td>
</tr>
<tr>
<td>V1-time spending(37)</td>
<td>0.30</td>
<td>0.65</td>
</tr>
<tr>
<td>V2-attempt number(44)</td>
<td>0.34</td>
<td>0.63</td>
</tr>
<tr>
<td>V3-prerequisite graph(38)</td>
<td>0.37</td>
<td>0.63</td>
</tr>
<tr>
<td>Baseline1-control group(39)</td>
<td>0.26</td>
<td>0.59</td>
</tr>
<tr>
<td>Baseline2-last semester(138)</td>
<td>0.32</td>
<td>0.65</td>
</tr>
<tr>
<td>First-time pass rate</td>
<td>0.26</td>
<td>0.09</td>
</tr>
</tbody>
</table>
Results of R3 - Potential gaming reduction

<table>
<thead>
<tr>
<th></th>
<th>Without intervention</th>
<th>With intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1-time spending (37)</td>
<td>0.30</td>
<td>0.08</td>
</tr>
<tr>
<td>V2-attempt number (44)</td>
<td>0.34</td>
<td>0.07</td>
</tr>
<tr>
<td>V3-prerequisite graph (38)</td>
<td>0.37</td>
<td>0.16</td>
</tr>
<tr>
<td>Baseline1-control group (39)</td>
<td>0.26</td>
<td>0.23</td>
</tr>
<tr>
<td>Baseline2-last semester (138)</td>
<td>0.32</td>
<td>0.16</td>
</tr>
<tr>
<td>First-time pass rate</td>
<td>0.26</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Drop more: V1-time spending, V2-attempt number, Baseline1-control group
Drop less: V3-prerequisite graph, Baseline2-last semester, First-time pass rate
Results of R3 - Questionnaires

• The mean scores are almost all above 4 (neither agree nor disagree), which means our designs can convey the information clearly, arouse students’ reflection on gaming behaviour, easy to understand to some extent, except that V1 seems not easy to understand with a mean score lower than 4.

• For V1, “too many components” (S1, S3, and S4), that “fonts are small” (S7), and that it is “not clear where you should start reading” (S7)

<table>
<thead>
<tr>
<th></th>
<th>Q1-Information conveyance</th>
<th>Q2-Reflection on gaming</th>
<th>Q3-Reflection on question-answering</th>
<th>Q4-Easy to understand</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>4.6(1.7)</td>
<td>4.3(1.8)</td>
<td>4.3(1.8)</td>
<td>3.7(1.9)</td>
</tr>
<tr>
<td>V2</td>
<td>5.2(1.5)</td>
<td>4.7(1.2)</td>
<td>4.4(1.3)</td>
<td>5.1(1.2)</td>
</tr>
<tr>
<td>V3</td>
<td>5.8(0.7)</td>
<td>5.0(1.2)</td>
<td>5.3(1.1)</td>
<td>4.7(1.8)</td>
</tr>
</tbody>
</table>
Results of RQ3 – Design considerations for reflective nudges in online learning

- Color is effective for alert and highlighting information
  
  “(For V3,) The green and red color are good stimuli, like the traffic light in the psychology area” – S2, female, 19.

- Perceived authenticity increases persuasiveness
  
  “(In V2,) Show it explicitly that the data (historical first-time pass rate) is from *** course from 2018 winter semester. People will be more sensitive.” – S5, male, 28.

- Connecting to peers may hurt people who are low self-esteem
  
  “Low self-esteem or hard-working students might get hurt by seeing this (their attempts more than the mean attempts).” – S1, male, 25

- Ensuring good grasp of information is critical
  
  “It takes me 4-5 seconds to understand, but it needs to reduce down to 2-3 seconds (for V1).” – S3, male, 23.
Conclusion

• Identified three common gaming contexts and designed persuasive visualizations

• Deployed our information visualizations in real world

• Summarized design considerations on reflective nudges in online learning

How can we present and utilize peers’ learning data on multiple questions to students?
Our works

Qlens: multi-step question analysis. VIS 2020 (conditionally accepted)

SeqDynamics: problem-solving dynamics analysis. Euro VIS, 2020

“Game the system”: learning behavior regulation. L@S, 2020

Empower educators

Problem-solving Data

Empower students

Micro level

Macro level

Peerlens: learning path planning. CHI, 2019
PeerLens: Peer-inspired Interactive Learning Path Planning in Online Question Pool

Meng Xia, Mingfei Sun, Huan Wei, Qing Chen, Yong Wang, Lei Shi, Huamin Qu, Xiaojuan Ma

CHI 2019
What is an online question pool?

- A collection of questions for learners to practice their knowledge online

Features of question pools

- No pre-determined syllabus
- A lengthy list indexed by their problem IDs
- Hidden intents

- Different learning scenarios
- One learner’s learning scenario may be changing

**Difficulty:** Determine an appropriate order in taking these online questions for their particular learning scenarios
Current situation

<table>
<thead>
<tr>
<th>Programming question pools</th>
<th>Has recommendation?</th>
</tr>
</thead>
<tbody>
<tr>
<td>AtCoder</td>
<td>NO</td>
</tr>
<tr>
<td>CodeChef</td>
<td>NO</td>
</tr>
<tr>
<td>CodeFights</td>
<td>NO</td>
</tr>
<tr>
<td>Codeforces</td>
<td>NO</td>
</tr>
<tr>
<td>Codewars</td>
<td>YES (Similar questions)</td>
</tr>
<tr>
<td>LeetCode</td>
<td>YES (Similar questions)</td>
</tr>
<tr>
<td>CodinGame</td>
<td>NO</td>
</tr>
<tr>
<td>Coderbyte</td>
<td>NO</td>
</tr>
<tr>
<td>CSAcademy</td>
<td>NO</td>
</tr>
<tr>
<td>HackerEarth</td>
<td>NO</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Programming question pools</th>
<th>Has recommendation?</th>
</tr>
</thead>
<tbody>
<tr>
<td>HackerRank</td>
<td>NO</td>
</tr>
<tr>
<td>Kattis</td>
<td>NO</td>
</tr>
<tr>
<td>uDebug</td>
<td>NO</td>
</tr>
<tr>
<td>OmegaUp</td>
<td>NO</td>
</tr>
<tr>
<td>Sphere Online Judge</td>
<td>NO</td>
</tr>
<tr>
<td>Topcoder</td>
<td>NO</td>
</tr>
<tr>
<td>Toph</td>
<td>NO</td>
</tr>
<tr>
<td>URI Online Judge</td>
<td>NO</td>
</tr>
<tr>
<td>UVa Online Judge</td>
<td>NO</td>
</tr>
</tbody>
</table>

**Demand:** planning personalized learning path in the context of existing list-based question pools
Related work: Educational Recommendation Techniques

Memory-based techniques
Continuously analyze current data \cite{Drachsler2008}

• Content-based \cite{Chu2011}, Collaborative Filtering \cite{Toledo2018}, Hybrid approach \cite{Salehi2013}

Model-based techniques
Utilize a large amount of historical data to model the learning process over time

• Deep learning models \cite{Piech2015}, other models, such as Markov Chain \cite{Rajapakse2005, Sarukkai2000, Huang2009}

\begin{itemize}
  \item Lack of information
  \item No explanation on the recommendations
\end{itemize}
A user-centered design process

• Four domain experts
  • Experts in online learning (E1, E2)
  • Online question pool users (S1, S2)

• Requirements gathering iteratively for three months
  R1: Find peers for a specific learning scenario.
  R2: Compare with peers’ performance.
  R3: Offer flexible learning path suggestions.
  R4: Provide convenient interaction and intuitive visual designs for learning path planning.
System overflow
Path Planning Engine: Learning Path Modeling

Submission type: the way a user interacts with a problem.

- Captures learners’ knowledge proficiency
- Enables the inference of question difficulty level
A given peer path \([ (X_{i_0}, E_{i_0}, t_{i_0}), \ldots, (X_{i_n}, E_{i_n}, t_{i_n}) ] \) corresponds to a state \( s = \{ X_{i_0}, X_{i_1}, \ldots, X_{i_n} \} \).

Markov Chain:

Popular path: \( X_1 \rightarrow X_3 \rightarrow X_4 \)

Challenging path: \( X_1 \rightarrow X_4 \)

Progressive path: \( X_3 \rightarrow X_4 \rightarrow X_1 \)
Regular Learning: regularly for a long time and solve 1-2 problems per day.

Intensive Learning: 1-3 months, solve 2-5 questions per day with high proficiency.

Advanced Learning: solve many problems per day in short time with high proficiency.

Yellow diamond plot: selected peers  Blue diamond plot: learner himself
Visual Design: Learning Path View
Visual Design: Learning Path View
Visual Design: Learning Path View
Visual Design: Learning Path View
Visual Design: Learning Path View

Submission Type
- 0: Tried only once and failed
- 0..0: Tried several times and failed
- 0..1: Tried several times and succeeded
- 0..1..: Tried, succeeded and validated
- 1: Tried once and succeed
- 1..: Succeeded and then validated

Slide

History Path

Challenging Path

Popular Path

Progressive Path
Visual Design: Learning Path View
Visual Design: Learning Path View
Evaluation: Experiment Design

Dataset:
A popular programming question pool
~4.6M submission records
~54K learners
~5K programming questions

Participants:
18 (7 females, 11 males, age:24±2.85), from a local computer science department

Systems:
S1. Full PeerLens
S2. Baseline system
S3. Primitive PeerLens
Evaluation: Experiment Design

**Within-subject:**
Counter balance the three learning scenarios and three systems

**Learning scenarios:**
L1. Basic programming practice
L2. Coding qualification test for IT company interviews
L3. International Programming Contest

**Tasks:**
1. Determine the starting question under a specific learning scenario
2. Find the next question to solve given an existing historical learning path
## Evaluation: Questionnaires

<table>
<thead>
<tr>
<th>Informativeness</th>
<th>Decision making</th>
<th>Visual design</th>
<th>System Usability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q4</td>
<td>Q7</td>
<td>Q9</td>
</tr>
<tr>
<td>The information needed to plan a learning path is easy to access.</td>
<td>The system was helpful for me to find a proper learning path for a specific learning scenario.</td>
<td>The learning path design is intuitive.</td>
<td>It was easy to learn the system.</td>
</tr>
<tr>
<td>Q2</td>
<td>Q5</td>
<td>Q8</td>
<td>Q10</td>
</tr>
<tr>
<td>The information needed to plan a learning path is rich.</td>
<td>I am confident that I find a suitable learning path for the learning scenario.</td>
<td>The learning path design helps me understand the suggested path.</td>
<td>It was easy to use the system.</td>
</tr>
<tr>
<td>Q3</td>
<td>Q6</td>
<td></td>
<td>Q11</td>
</tr>
<tr>
<td>The information is sufficient to plan a learning path.</td>
<td>The system helps make adjustment according to previous performance.</td>
<td></td>
<td>I would like to recommend this system to others.</td>
</tr>
</tbody>
</table>
Results

Informativeness and decision-making efficacy

- Primitive and Full PeerLens > Baseline
- Information richness & sufficiency: Full PeerLens > Primitive
- Information accessibility: No significant differences between Full and Primitive
- Decision-making metrics: Full PeerLens > Primitive
Results

Visual designs and system usability

• Intuitiveness & comprehension: Full PeerLens > Primitive

• Easy to learn & use: No significant difference between Full and Primitive

• Recommendation: Full PeerLens > Primitive
Conclusion

- A novel visual analytics system
- A novel zipper-like visualization
- A within-subject user experiment
Our works

Qlens: multi-step question analysis. VIS 2020 (conditionally accepted)

SeqDynamics: problem-solving dynamics analysis. Euro VIS, 2020

“Game the system”: learning behavior regulation. L@S, 2020

Empower educators

Problem-solving Data

Empower students

Micro level

Macro level

1

2

3

4

Peerlens: learning path planning. CHI, 2019
Discussion - Methodology

Domain situation: formative studies to understand target users’ requirements: educators and students

Data/task abstraction:
Data: event sequence data
Tasks: representation, summarization, and comparison

Problem-solving behavior Modelling:
represent the sequences from levels of detail
Question: difficulty level, test knowledge
Students: cognitive skills, non-cognitive traits

Visual encoding: justify alternative designs; address interaction; show the data step by step

Iterative design with educators and students
Lab study, deployment, and post-study interviews
Pipeline for Visualization of Problem-solving behaviors:

1. Design a workflow (i.e., from which level to which level) for the analysis process according to users and tasks.

<table>
<thead>
<tr>
<th>Level</th>
<th>Data</th>
<th>Tasks (examples)</th>
<th>Views</th>
</tr>
</thead>
<tbody>
<tr>
<td>many to many</td>
<td>all students, all questions</td>
<td>Select best candidates</td>
<td>Over view</td>
</tr>
<tr>
<td>(macro)</td>
<td></td>
<td></td>
<td>Main view</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Comparison view</td>
</tr>
<tr>
<td>one to many</td>
<td>all students, one question</td>
<td>Question design</td>
<td>Main view</td>
</tr>
<tr>
<td>(micro)</td>
<td></td>
<td></td>
<td>Comparison view</td>
</tr>
<tr>
<td></td>
<td>one student, all questions</td>
<td>Personalized instruction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>many (one group) students, one question</td>
<td>Comparison among groups</td>
<td></td>
</tr>
<tr>
<td></td>
<td>one student, many (one group) of questions</td>
<td>Comparison among students</td>
<td></td>
</tr>
<tr>
<td>one to one</td>
<td>one student, one question</td>
<td>On the fly guidance</td>
<td>Main view</td>
</tr>
<tr>
<td>(micro)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Pipeline for Visualization of Problem-solving behaviors:

2. Design the visualization:

   Overview:
   • **Summarize the features** of students or the questions to facilitate the level jump
   • If one attribute, use list or bar chart (QLens); If more attributes, consider using glyph (SeqDynamics)

Main view:
• If the problem-solving sequence is **order-oriented**, model the sequence using state and transition (QLens, PeerLens)
• If the problem-solving sequence is **time-oriented**, model the sequence on different time bins (SeqDynamics, Game the system)

Comparison view:
• Embedded in one view (PeerLens)
• Separated using another view (QLens, SeqDynamics)
Discussion: Design Considerations

Online problem-solving:
• Students are **eager for more guidance** in their learning online
• Students have different perception of the same data, thus **the inference of students’ motivation, personality, phycology state** are also important, apart from ability.

Visualization:
• **Color** is the most effective channel across our designed systems
  • They are frequently used for **alert or highlighting information**
• For both students and educator
  • It is required to provide intuitive designs
  • It is vital to **show information step by step**, even in one single view
• For students, they need simpler visual designs to understand quicker
Future Work

Empower educators

Collect Data: Infer students’ psychology states from multiple channels

Methodology:
1. Refine the problem-solving process modeling with learning scientists
2. Apply more advanced AI techniques

Applications:
1. Providing on-the-fly guidance
2. Explore collaborative problem-solving behaviors

Evaluation:
1. Deploy and test proposed systems in the real-world setting for a longer time
2. More rigorous studies to test the effects of education data visualization

Empower students
Publications

- **Meng Xia**, Reshika Palaniyappan Velumani, Panpan Xu, Yong Wang, Huamin Qu, Xiaojuan Ma, QLens: Visual Analytics of Multi-step Problem-solving Behaviors for Improving Question Design, Conditionally accepted, IEEE VIS 2020 (TVCG track)

- **Meng Xia**, Yuya Asano, Joseph Jay Williams, Huamin Qu, Xiaojuan Ma, Using Information Visualization to Promote Students’ Reflection on “Gaming the system” in Online Learning, L@S 2020

- **Meng Xia**, Min Xu, Chuan-en Lin, Ta-ying Cheng, Huamin Qu, Xiaojuan Ma, SeqDynamics: Visual Analytics for Evaluating Online Problem-solving Dynamics, EuroVis 2020

- Huan Wei, Haotian Li, **Meng Xia**, Yong Wang, Huamin Qu, Predicting Student Performance in Interactive Online Question Pools Using Mouse Interactions, ACM LAK 2020 (Learning Analytics & Knowledge)

- **Meng Xia**, Huan Wei, Min Xu, Leo Yu Ho Lo, Yong Wang, Rong Zhang, Huamin Qu, Visual Analytics of Student Learning Behaviors on K-12 Mathematics E-learning Platforms, Poster, IEEE VIS 2019 Posters, Best Poster Award

- **Meng Xia**, Mingfei Sun, Huan Wei, Qing Chen, Yong Wang, Lei Shi, Huamin Qu, Xiaojuan Ma, PeerLens: Peer-inspired Interactive Learning Path Planning in Online Question Pool, video ACM CHI 2019

- **Meng Xia**, Rong Zhang, Ren Peng, Jinhui Yu, Generation of Thangka Relief from Line Drawings, SCIENTIA SINICA Informationis 2018

- Ke Xu, **Meng Xia**, Xing Mu, Yun Wang, Nan Cao, EnsembleLens: Ensemble-based Visual Exploration of Anomaly Detection Algorithms with Multidimensional Data, TVCG 2018

- Zhenhui Peng, Jeehoon Yoo, **Meng Xia**, Sunghun Kim, Xiaojuan Ma, Exploring How Software Developers Work with Mention Bot in GitHub, Chinese CHI 2018

- Mingfei Sun, Yiqing Mou, Hongwen Xie, **Meng Xia**, Michelle Wong, Xiaojuan Ma, Estimating Emotional Intensity from Body Poses for Human-Robot Interaction, IEEE SMC 2018, demo
Acknowledgement

Prof. Huamin Qu

Prof. Xiaojuan Ma
Acknowledgement

Prof. Jeseph Jay Williams
Bridge the Gap between Educators and Students in Online Learning: 
A Visualization Approach based on Problem-solving Data 

Thank you! 
Q & A