

Enhancing Personalized Learning Through Interactive Visual Analytics Systems

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Outline

- Introduction
 - Background
 - Definition
 - Challenges
 - Research Question
 - Motivation
- Taxonomy
- Future Work
- Take-home Message

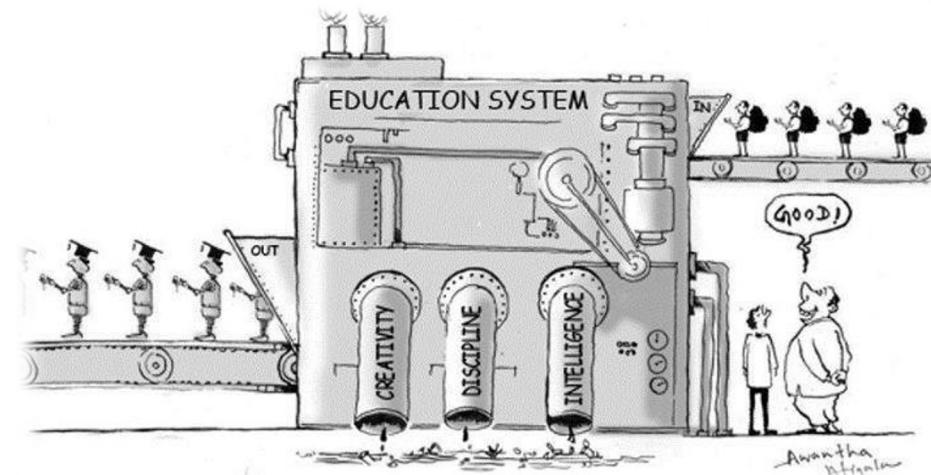
Background

Modern schooling often utilize a **"one-size-fits-all"** approach:

- Predetermined curricula,
- Standardized syllabi,
- Uniformly assigned homework,
- Low instructor-student ratio
- ...



CIT Course Syllabus Data Structures and Algorithms	
Module	Name
Week 1	• Introduction to Computer Science
Week 2	• Data Structures
Week 3	• Algorithms
Week 4	• Recursion
Week 5	• Dynamic Programming
Week 6	• Greedy Algorithms
Week 7	• Graphs
Week 8	• Trees
Week 9	• Hash Tables
Week 10	• Sorting
Week 11	• Searching
Week 12	• Advanced Data Structures
Week 13	• Advanced Algorithms
Week 14	• Machine Learning
Week 15	• Deep Learning
Week 16	• Reinforcement Learning
Week 17	• Natural Language Processing
Week 18	• Computer Vision
Week 19	• Robotics
Week 20	• Bioinformatics
Week 21	• Cryptocurrency
Week 22	• Blockchain
Week 23	• Quantum Computing
Week 24	• Fuzzy Logic
Week 25	• Fuzzy Logic
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Week 27	• Fuzzy Logic
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Week 200	• Fuzzy Logic

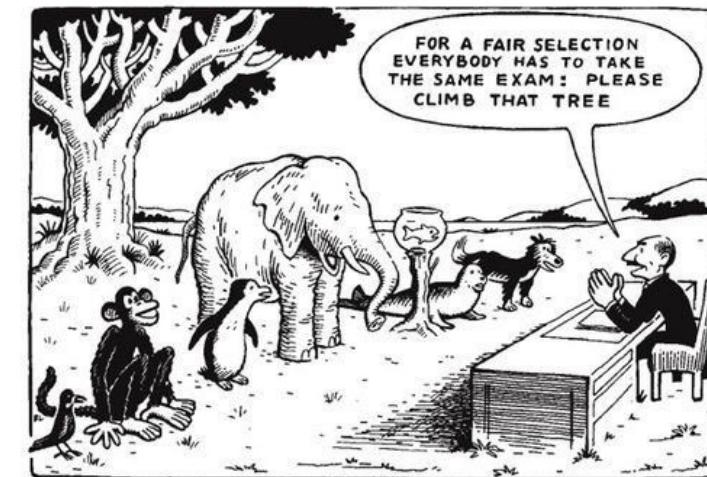


D. Onah, J. Sinclair, and R. Boyatt. (2014). Dropout Rates Of Massive Open Online Courses: Behavioural Patterns. In Proceedings of International Conference on Education and New Learning Technologies. 5825–5834

Painpoints of Education

However, we overlooks the fact that **students vary considerably** in their:

- Abilities,
- Learning preferences,
- Prior knowledge,
- Interests,
- Educational goals,
- ...

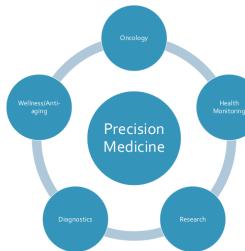


Need a truly tailored educational environment!

A Shemshack, JM Spector. (2020). A systematic literature review of personalized learning terms. Smart Learning Environments

What is Personalized Learning

Tailored to an individual learner's **needs** or **conditions** and **adaptable** to the learner's evolving skills and knowledge.



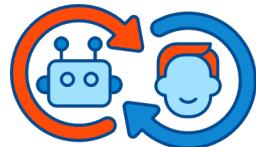
Provide a **learner-centered** learning environment

- ❖ Epstein, Sam; Epstein, Beryl (1961). *The First Book of Teaching Machines*
- ❖ A Shemshack, JM Spector. (2020). *A systematic literature review of personalized learning terms*. Smart Learning Environments

Challenges

- How can instructors **balance** personalization and standardization?
- How can instructors track and **review** individual learning progress?
- How can students **explore** best-fit personalized learning pace?
- ...

**Require human involvement
Not a pure algorithmic problem**

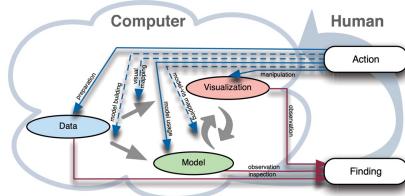


Matthew L. Bernacki. (2021). Educational Psychology Review: A Systematic Review of Research on Personalized Learning: Personalized by Whom, to What, How, and for What Purpose(s)?,

Research Question

How we effectively involve human in personalized learning implementation?

Enhancing personalized learning through interactive visual analytics systems!



Automated analysis + Interactive visualizations

D Keim, G Andrienko, JD Fekete. (2008). *Visual Analytics: Definition, Process, and Challenges*. Information Visualization.

D Sacha, A Stoffel. (2014). *Knowledge Generation Model for Visual Analytics*. IEEE transactions on visualization and computer graphics.

Motivation

To enhance the execution of personalized learning, what can we do with the help of interactive VA systems?

- **Who** are the core stakeholders involved in the implementation of PL?
- **Why** they use the VA systems to facilitate PL?
- **How** do they accomplish their objectives and enhance PL?

Outline

- Introduction
- **Taxonomy**
 - Paper Selection & Citation Graph
 - Taxonomy Overview
 - Learner Side
 - Instructor Side
- Future Work
- Take-home Message

Paper Selection

Resource:

Google Scholar, IEEE Xplore, ACM Digital Library, Springer AIED Conference, ...

- Keywords searching: "adaptive learning", "personalized learning", "customized learning", "visual analytics", "visualization" ..
- All Metadata matching
- Exchangeable keywords combination
- Cite and be cited
- Related Paper

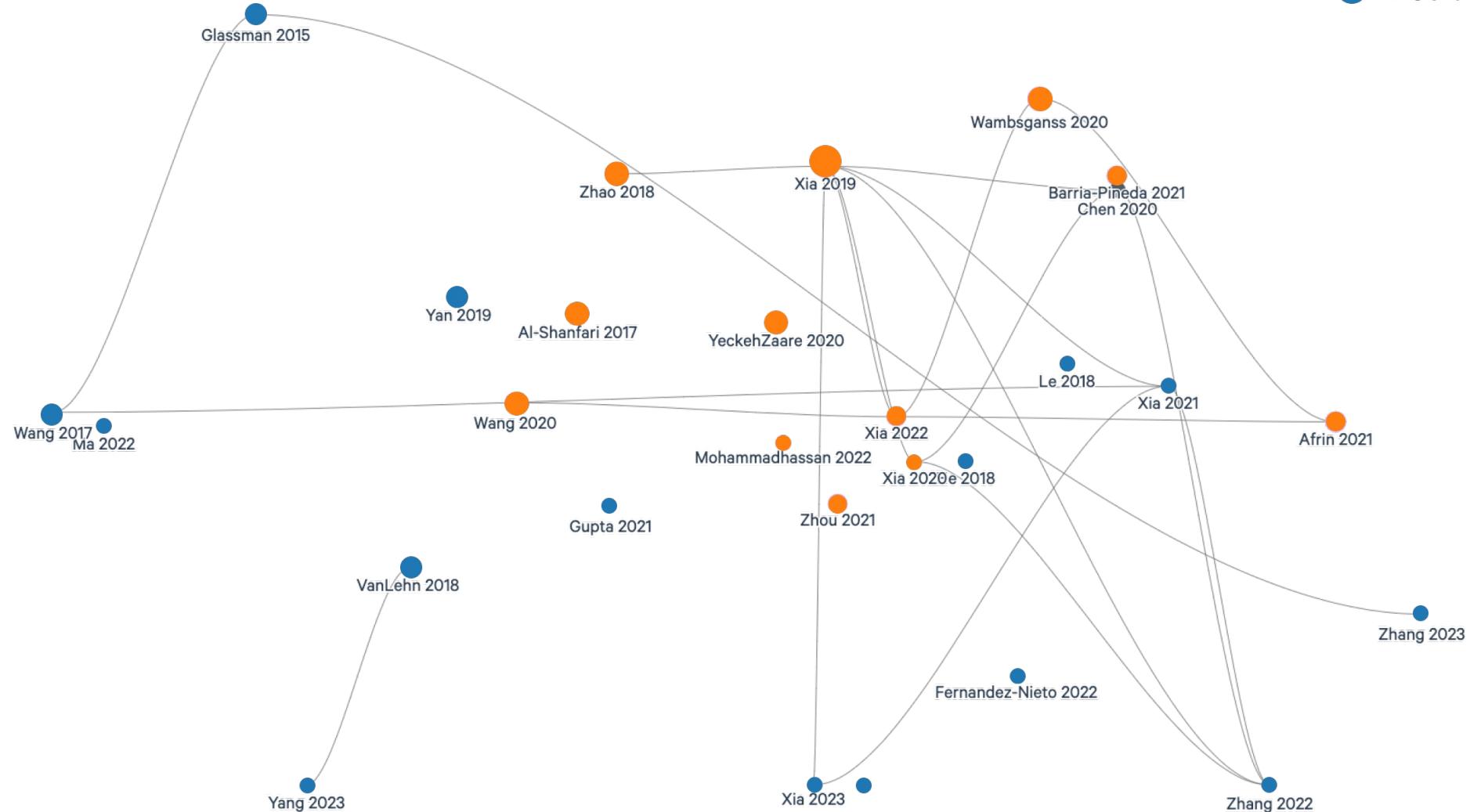
Results:

300+ => **28** papers after focus & quality filtering

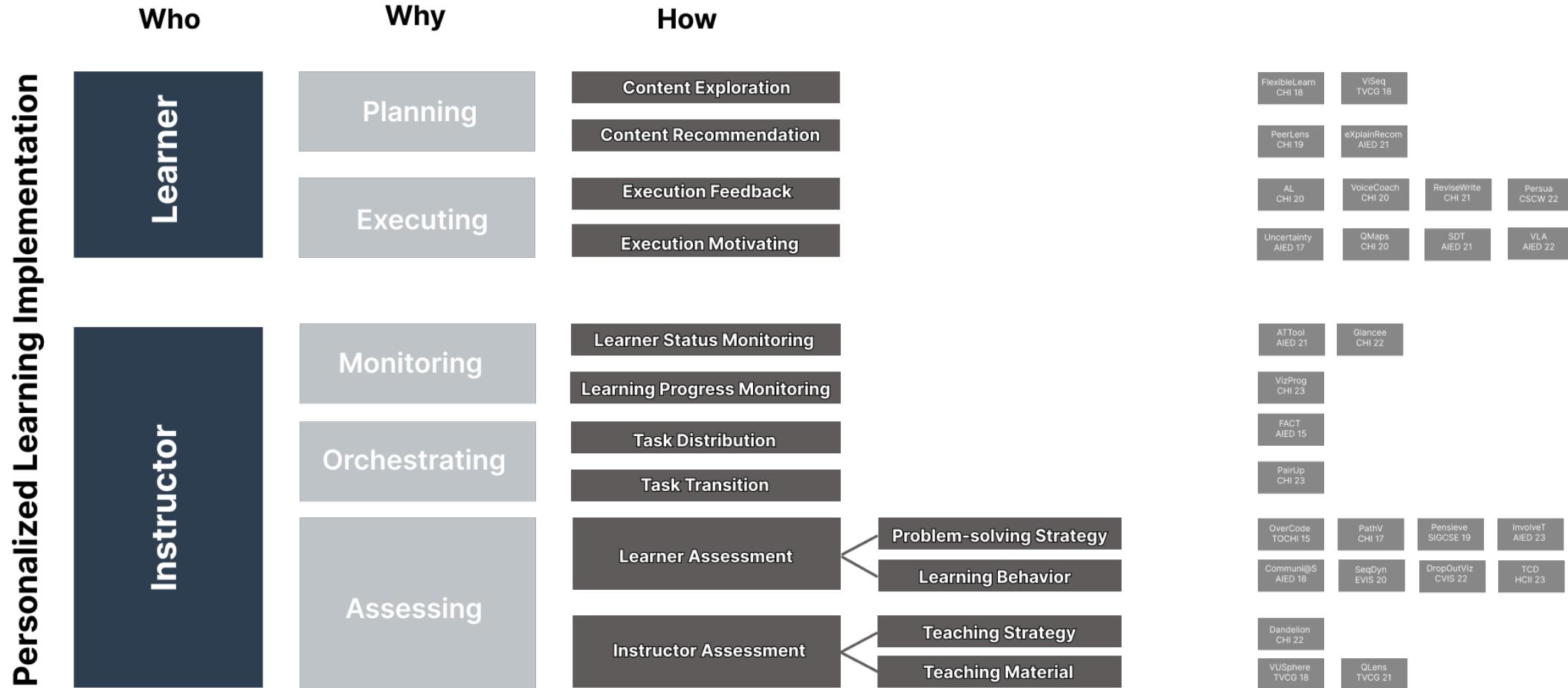


Citation Graph

● Learner
● Instructor

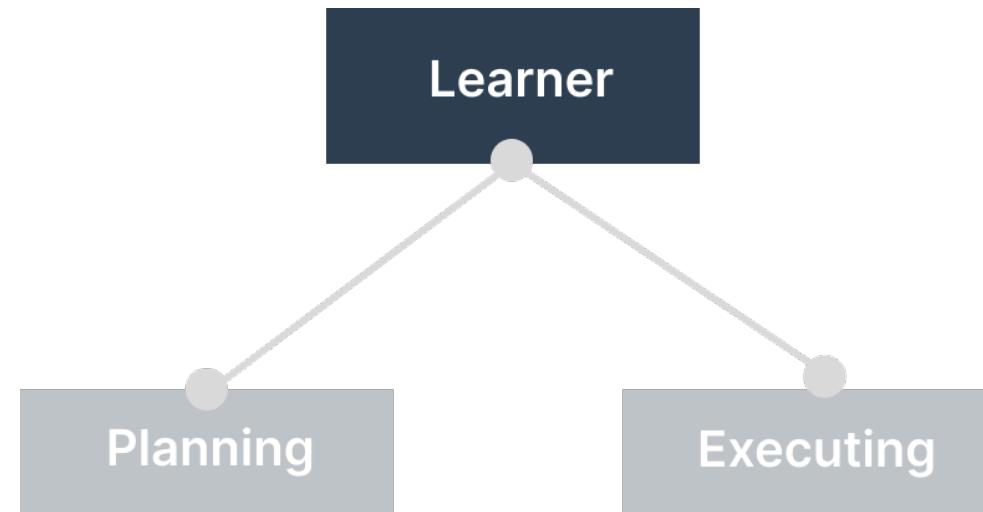


Taxonomy



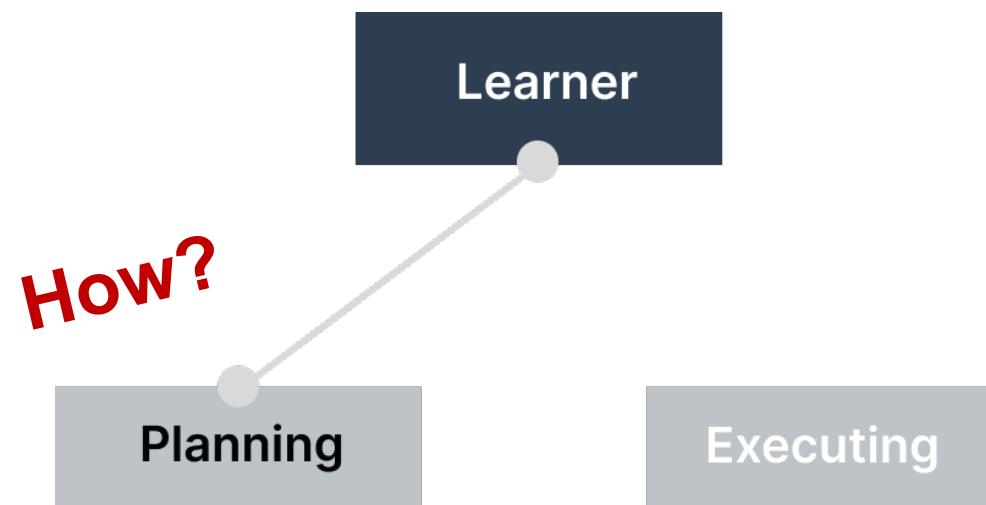
Learner

- **Why** do learner use the VA systems to support personalized learning?



Planning

Definition: Learners explore and determine **what to learn** for their particular needs or learning scenario.



Wong, L. H., & Looi, C. K. (2011). A survey of optimized learning pathway planning and assessment paper generation with swarm intelligence. In *Intelligent tutoring systems in e-learning environments: Design, implementation and evaluation* (pp. 285-302). IGI Global.

Plan what to learn

Jimmy, a year-4 business student who takes the course COMP3711 (Algorithm) for his minor degree.

Why do these algorithms, e.g., Dynamic Programming matter in real life ?

MOOC Videos follow syllabus sequence!

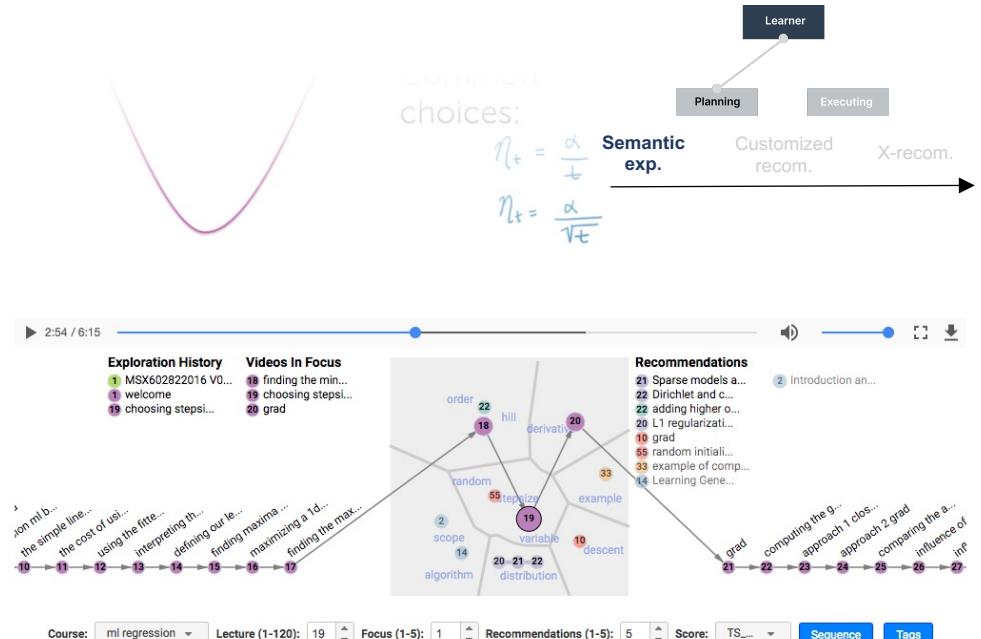


How to plan a learning that extent to coherent contents from different courses to get a comprehensive understanding?

Semantic Exploration

Domain Problem

Explore lecture videos based on the **concept map** by considering both **semantic coherent** and sequential inter-topic relationships.

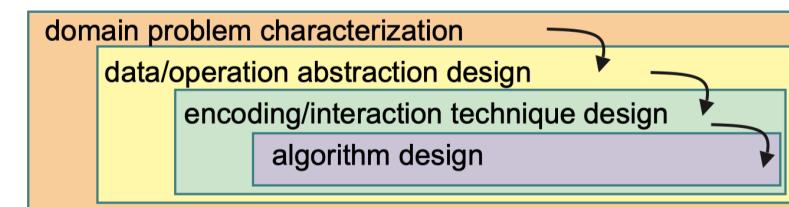


Zhao, J., Bhatt, C., Cooper, M., & Shamma, D. A. (2018, April). Flexible learning with semantic visual exploration and sequence-based recommendation of MOOC videos. In *Proceedings of the 2018 CHI conference on human factors in computing systems* (pp. 1-13).

Pedagogical theory

Interactive concept map allows for more personalized learning behaviors [1].

[1] J. D. Novak and D. B. Gowin. 1984. Learning how to learn. Cambridge University Press.



Munzner, T. (2009). A nested model for visualization design and validation. *IEEE transactions on visualization and computer graphics*, 15(6), 921-928.

Semantic Exploration

Videos In Focus

- 25 optional improv...
- 26 a brief recap
- 27 the goal of clu...
- 28 an unsupervised...
- 29 hope for unsupe...

...ng more b...
searching neigh...
ish in higher d...

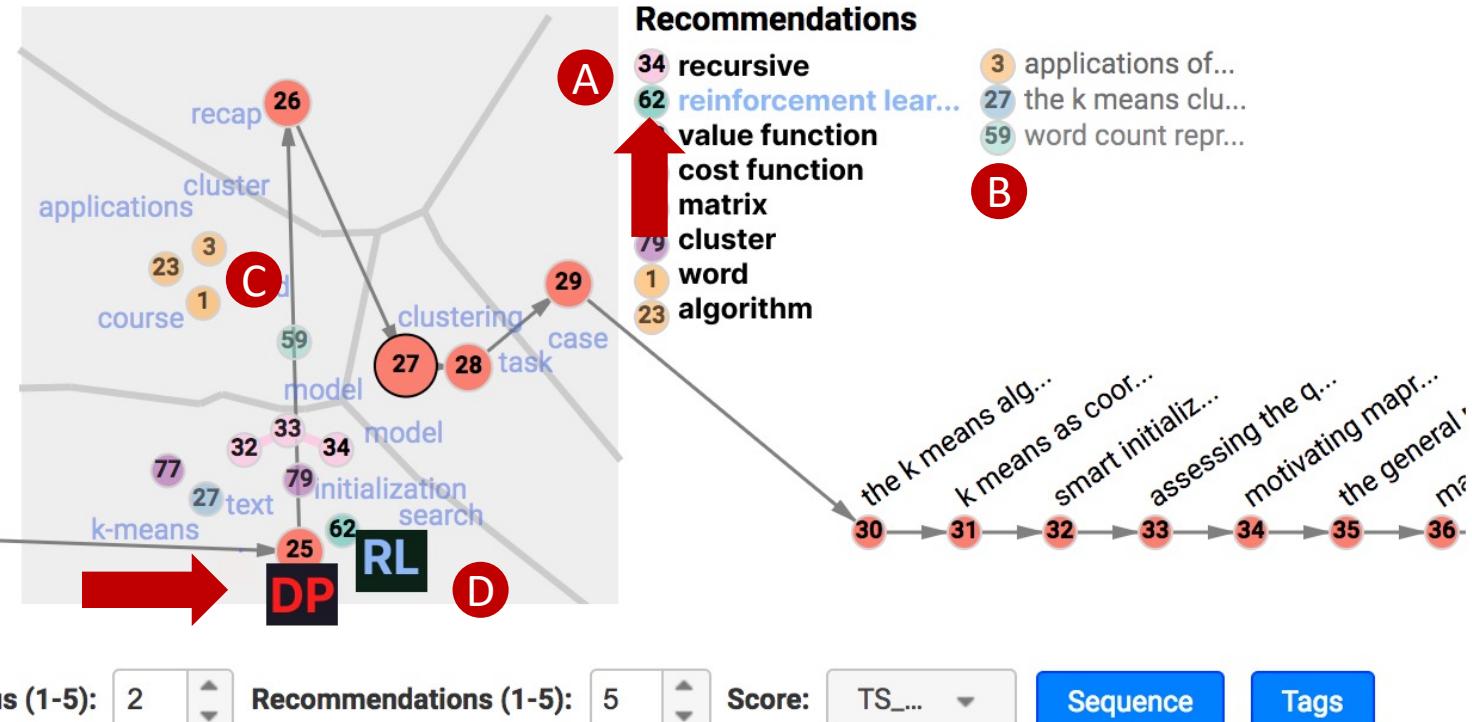
ture (1-79): 27

Focus (1-5): 2

Recommendations (1-5): 5

Score: TS... ▾

Sequence Tags



Zhao, J., Bhatt, C., Cooper, M., & Shamma, D. A. (2018, April). Flexible learning with semantic visual exploration and sequence-based recommendation of MOOC videos. In *Proceedings of the 2018 CHI conference on human factors in computing systems* (pp. 1-13).

Data

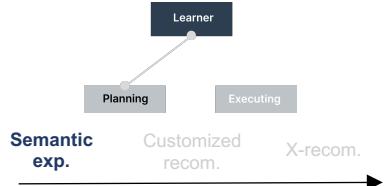
Text transcripts (**not personal**, unstructured)
Course syllabi (**not personal**, semi-structured)

Encoding

Color & opacity: course & rank (A)(B)
Distance: content relevance (C)
Regions: semantic coherence (D)

Algorithm

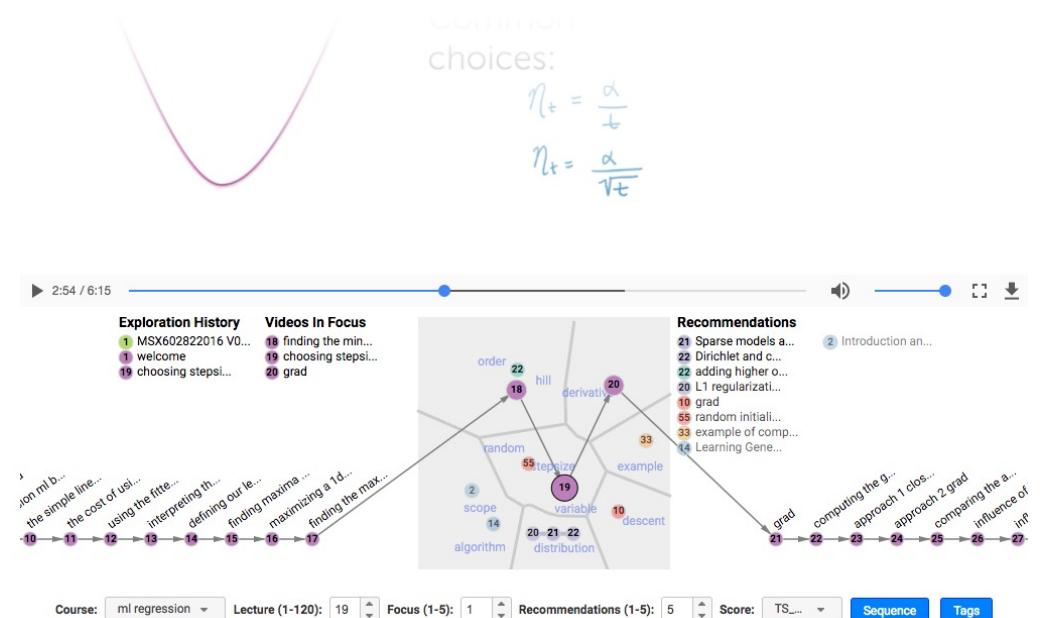
Multi-dimensional scaling
TF-IDF; TKS & TNS (sequential rule mining)



Semantic Exploration

Novelty

Concept-map based exploration from both **content semantics** and sequential inter-topic relationships.



Limitation

No **learner data** analysis used.

Zhao, J., Bhatt, C., Cooper, M., & Shamma, D. A. (2018, April). Flexible learning with semantic visual exploration and sequence-based recommendation of MOOC videos. In *Proceedings of the 2018 CHI conference on human factors in computing systems* (pp. 1-13).

Planning

Near the end of semester, Jimmy need to practice for final exam.
He just need to pass.

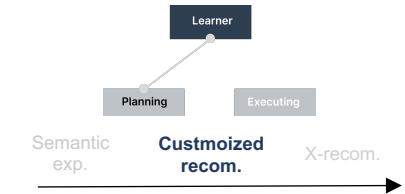


Leetcode questions are too much!

How to plan what to practice based on Jimmy's needs?

#	Title	Solution	Acceptance	Difficulty	Frequency
✓ 85	Maximal Rectangle	33.0%	Hard	<div style="width: 20%;"></div>	
✓ 621	Task Scheduler	45.2%	Medium	<div style="width: 45.2%;"></div>	
✓ 412	Fizz Buzz	59.3%	Easy	<div style="width: 59.3%;"></div>	
✓ 41	First Missing Positive	28.6%	Hard	<div style="width: 28.6%;"></div>	
✓ 54	Spiral Matrix	30.2%	Medium	<div style="width: 30.2%;"></div>	
642	Design Search Autocomplete System	37.1%	Hard	<div style="width: 37.1%;"></div>	
✓ 344	Reverse String	63.1%	Easy	<div style="width: 63.1%;"></div>	
✓ 127	Word Ladder	23.7%	Medium	<div style="width: 23.7%;"></div>	
124	Binary Tree Maximum Path Sum	29.8%	Hard	<div style="width: 29.8%;"></div>	
✓ 336	Palindrome Pairs	30.7%	Hard	<div style="width: 30.7%;"></div>	
✓ 141	Linked List Cycle	36.5%	Easy	<div style="width: 36.5%;"></div>	
193	Valid Phone Numbers	25.1%	Easy	<div style="width: 25.1%;"></div>	

Customized Recommendation

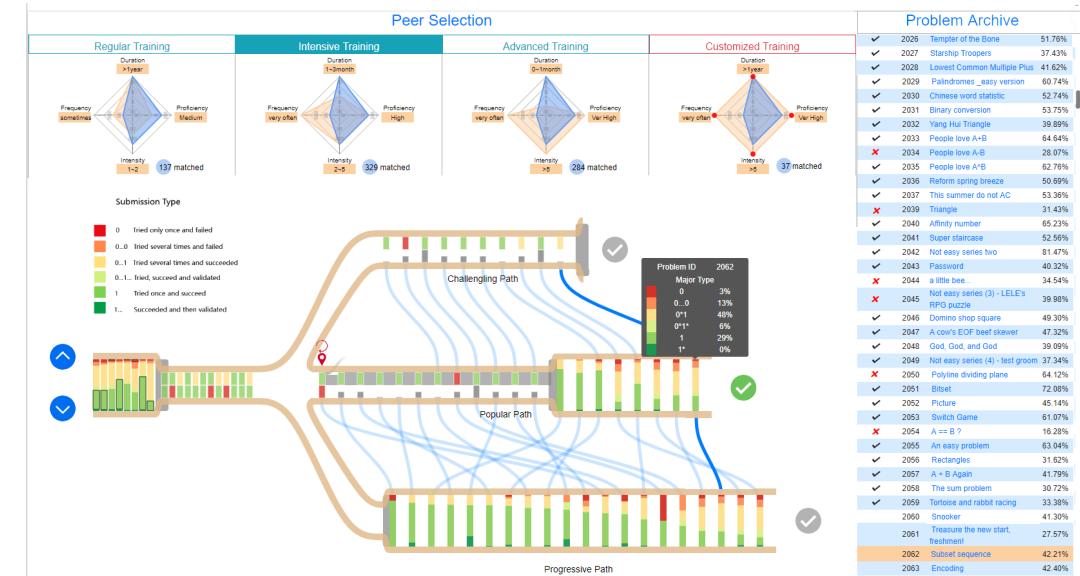


Domain Problem

Use peer data as source of **recommendation** to customize learning path planning based on their goals and learning scenario.

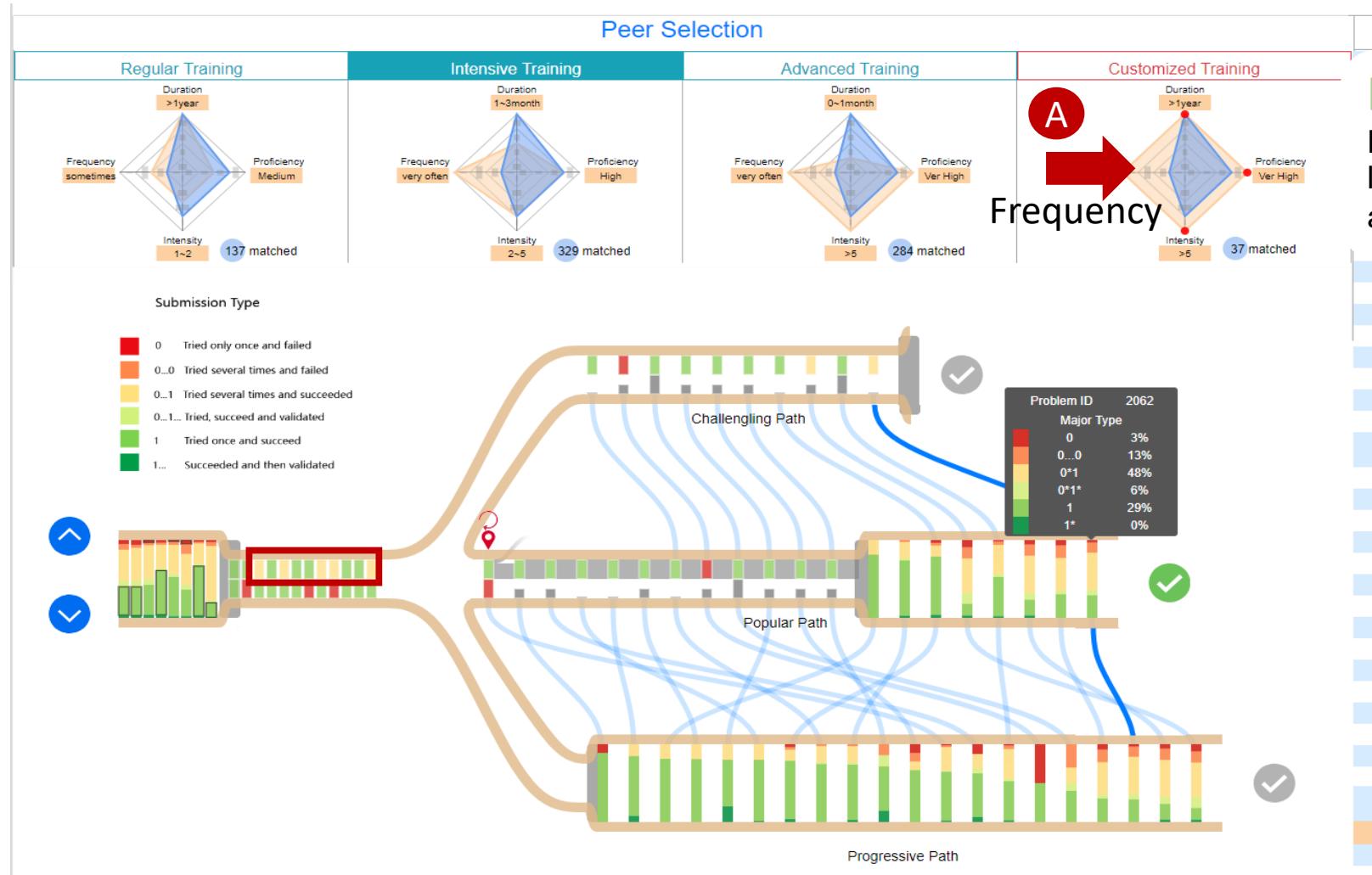
Pedagogical theory

Not explicitly mentioned



Xia, M., Sun, M., Wei, H., Chen, Q., Wang, Y., Shi, L., ... & Ma, X. (2019, May). Peerlens: Peer-inspired interactive learning path planning in online question pool. In *Proceedings of the 2019 CHI conference on human factors in computing systems* (pp. 1-12).

Customized Recommendation

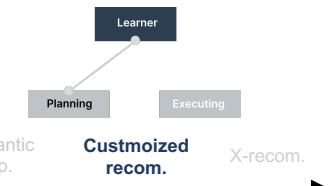


Problem Archive

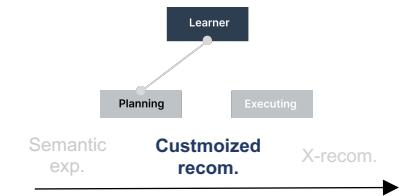
Encoding

Diamond plot with color:
learner/peer's learning
attributes (A)

✓ 2036 Reform spring breeze	50.69%
✓ 2037 This summer do not AC	53.36%
✗ 2039 Triangle	31.43%
✓ 2040 Affinity number	65.23%
✓ 2041 Super staircase	52.56%
✓ 2042 Not easy series two	81.47%
✓ 2043 Password	40.32%
✗ 2044 a little bee...	34.54%
✗ 2045 Not easy series (3) - LELE's RPG puzzle	39.98%
✓ 2046 Domino shop square	49.30%
✓ 2047 A cow's EOF beef skewer	47.32%
✓ 2048 God, God, and God	39.09%
✓ 2049 Not easy series (4) - test groom	37.34%
✗ 2050 Polyline dividing plane	64.12%
✓ 2051 Bitset	72.08%
✓ 2052 Picture	45.14%
✓ 2053 Switch Game	61.07%
✗ 2054 A == B ?	16.28%
✓ 2055 An easy problem	63.04%
✓ 2056 Rectangles	31.62%
✓ 2057 A + B Again	41.79%
✓ 2058 The sum problem	30.72%
✓ 2059 Tortoise and rabbit racing	33.38%
2060 Snooker	41.30%
2061 Treasure the new start, freshmen!	27.57%
2062 Subset sequence	42.21%
2063 Encoding	42.40%



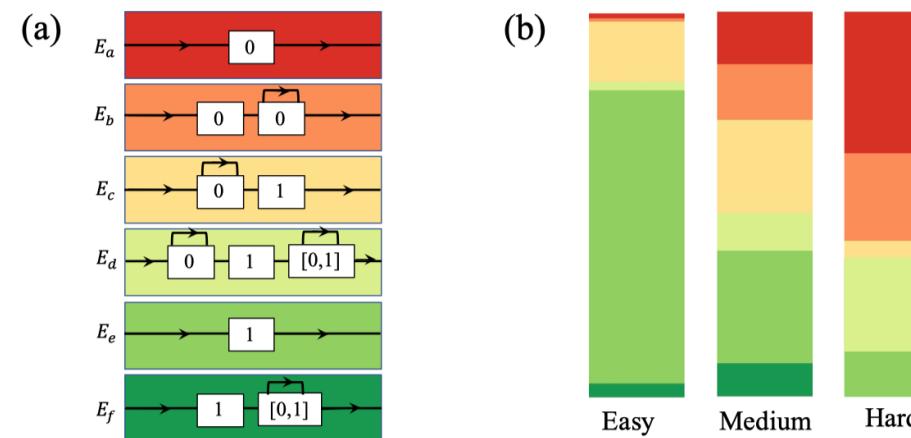
Customized Recommendation



Data

Students' basic info (**personal**, tabular data)
 Problem submission log (**personal**)

=> **Submission type** (categorical)
 => **Submission event** (event sequence)



Ea: One failed attempt without success

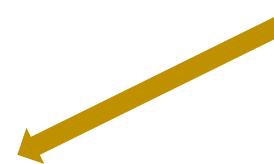
Eb: Multiple failed attempts without success

Ec: Multiple failed attempts followed by one success

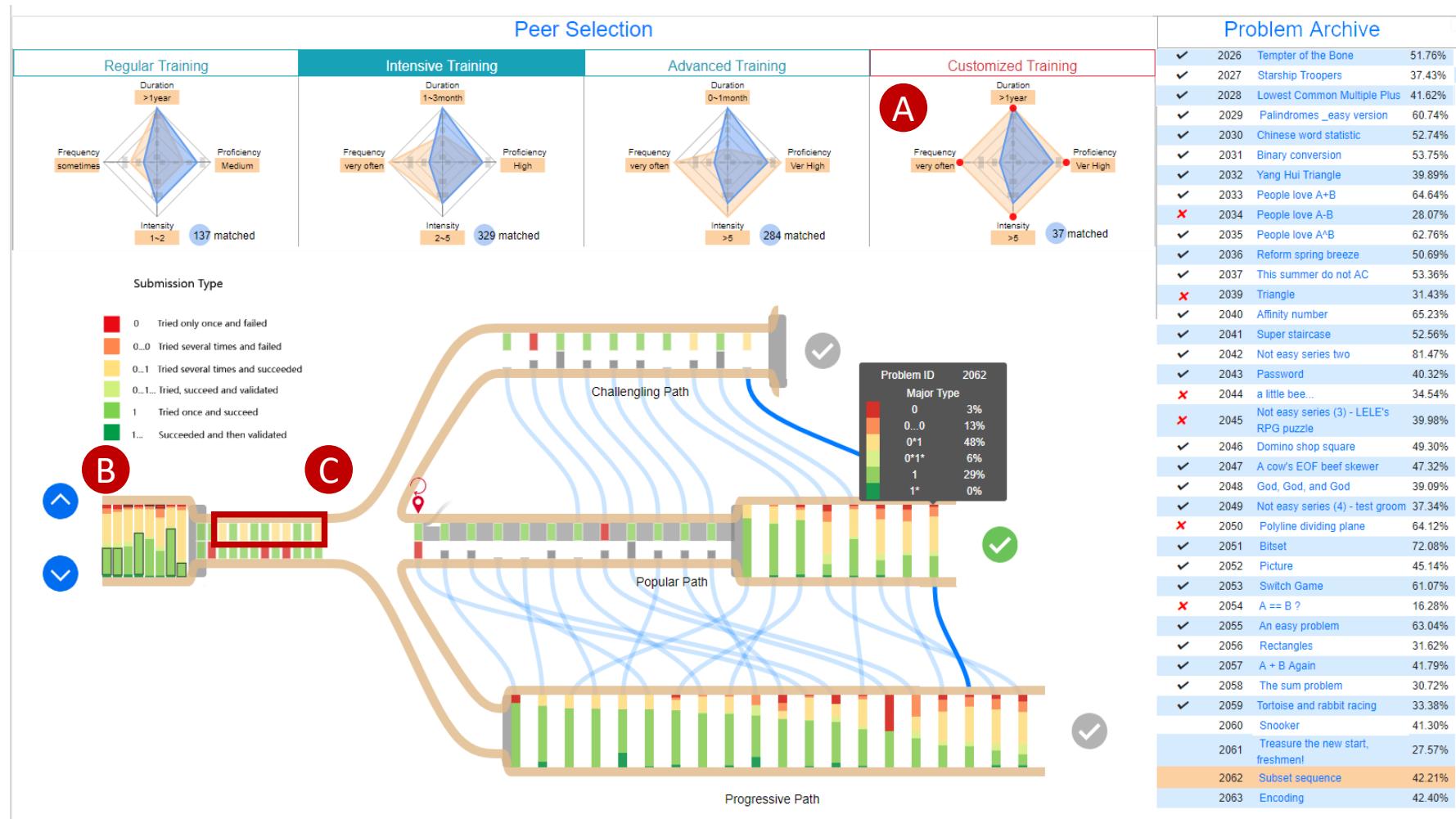
Ed: Multiple failed attempts followed by one success and more attempts

Ee: One success without further attempts

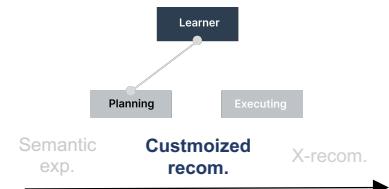
Ef: One success followed by more attempts.



Customized Recommendation



Xia, M., Sun, M., Wei, H., Chen, Q., Wang, Y., Shi, L., ... & Ma, X. (2019, May). Peerlens: Peer-inspired interactive learning path planning in online question pool. In *Proceedings of the 2019 CHI conference on human factors in computing systems* (pp. 1-12).



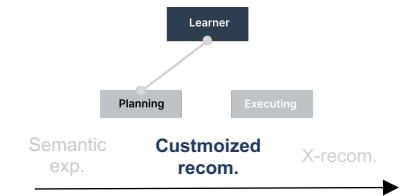
Algorithm Markov Chain

Encoding
Diamond plot with color: learner/peer's learning attributes (A)

Stacked bar: a question with its submission type (B)

Zipper-like visual metaphor: historical learning path (C)

Customized Recommendation

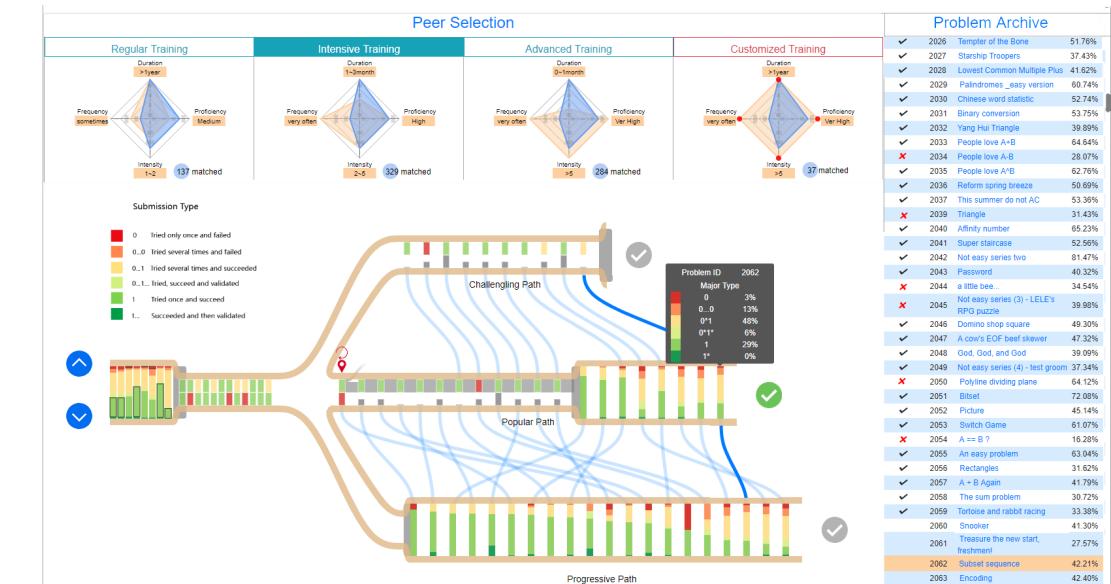


Novelty

Recommend customized question sequence base on the exercise history & submission type of selected peers in similar learning scenario.

Limitation

Only considers the **existing** peer's learning paths regardless of any **semantic meanings** like learner's concept mastery level.



Xia, M., Sun, M., Wei, H., Chen, Q., Wang, Y., Shi, L., ... & Ma, X. (2019, May). Peerlens: Peer-inspired interactive learning path planning in online question pool. In *Proceedings of the 2019 CHI conference on human factors in computing systems* (pp. 1-12).

Planning

Only two days before final, Jimmy need to do a quick review for his weakness.

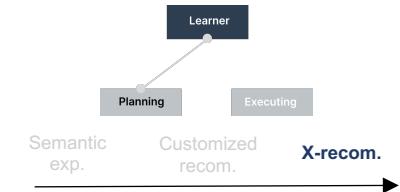


How to know Jimmy's knowledge level and plan what to review in the last minutes?



Weakness

X-Learner Modelling



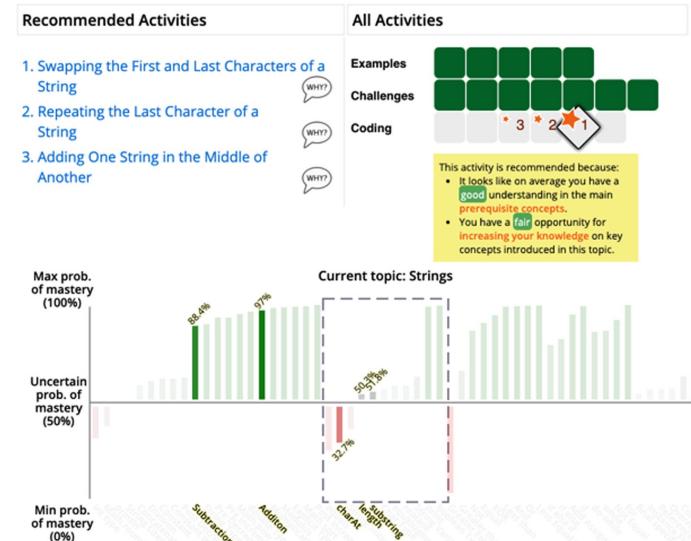
Domain Problem

Activities recommendation with visual and verbal **explanation**.

Personalized recommendation based on knowledge mastery level.

Pedagogical theory

Learner Models are model representations of a learner's knowledge [1].
Open Learner Models could serve promote adaptive educational systems [2].

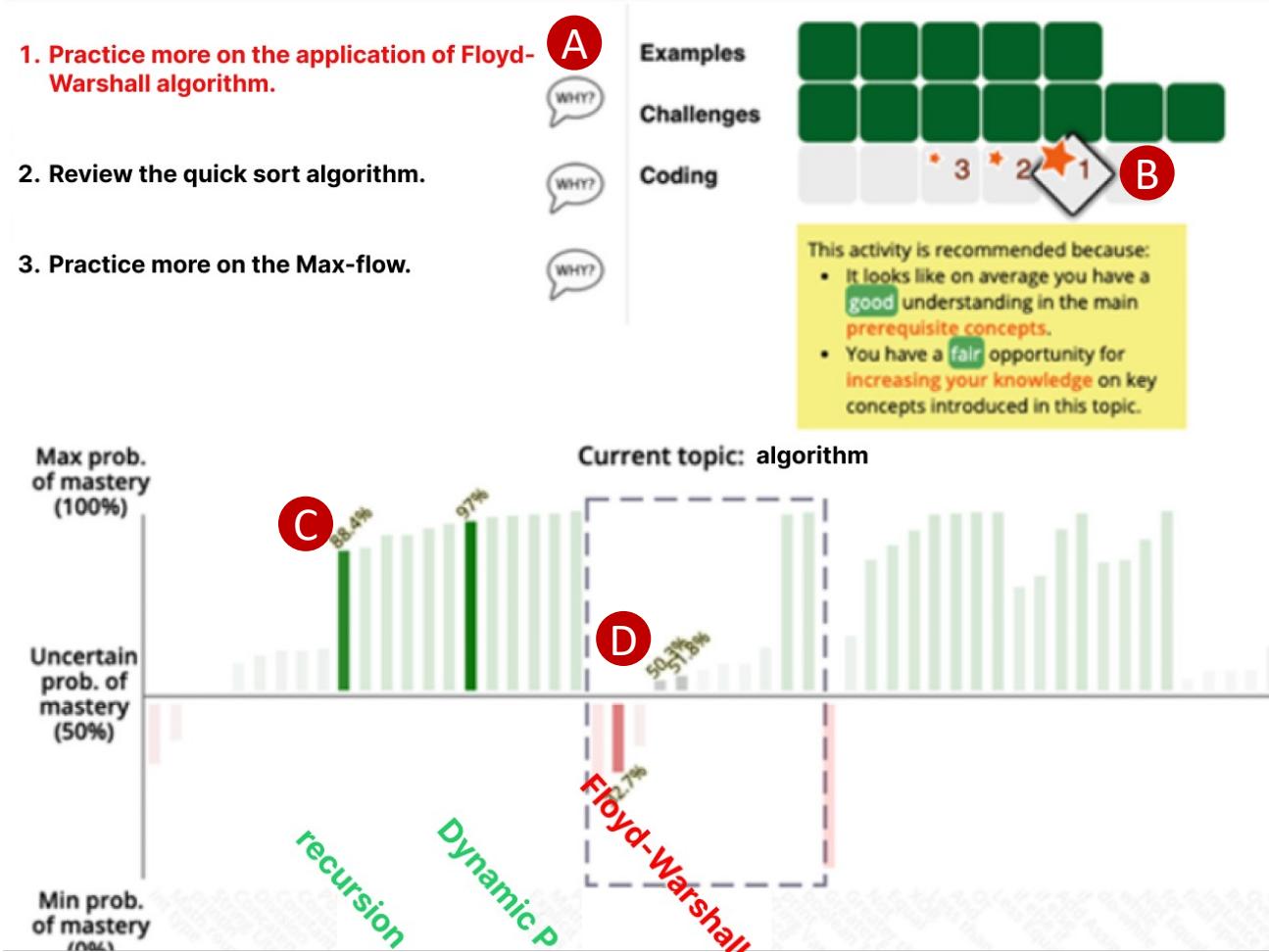


Barria-Pineda, J., Akhuseyinoglu, K., Želem-Ćelap, S., Brusilovsky, P., Milicevic, A. K., & Ivanovic, M. (2021, June). Explainable recommendations in a personalized programming practice system. In *International conference on artificial intelligence in education* (pp. 64-76). Cham: Springer International Publishing.

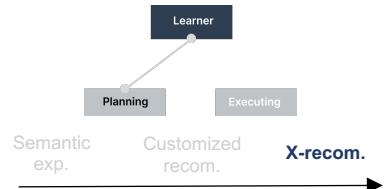
[1] Dillenbourg, P., & Self, J. (1992). A framework for learner modelling. *Interactive Learning Environments*, 2(2), 111-137.

[2] Bull, S., Kay, J.: SMILI: a framework for interfaces to learning data in open learner models, learning analytics and related fields. *Int. J. Artif. Intell. Educ.* 26(1), 29331 (2016)

X-Recommendation



Barria-Pineda, J., Akhuseyinoglu, K., Železný-Celap, S., Brusilovsky, P., Milicevic, A. K., & Ivanovic, M. (2021, June). Explainable recommendations in a personalized programming practice system. In *International conference on artificial intelligence in education* (pp. 64-76). Cham: Springer International Publishing.



Data
Personal learning log (Structured)

Algorithm
Bayesian Network

Encoding
Hover over for explanations(A)
Size: activity priority(B)
Color & height: concept-level mastery estimation(C)
Bar's color opacity and dash region distinguish "prerequisite" and "target knowledge"(D)

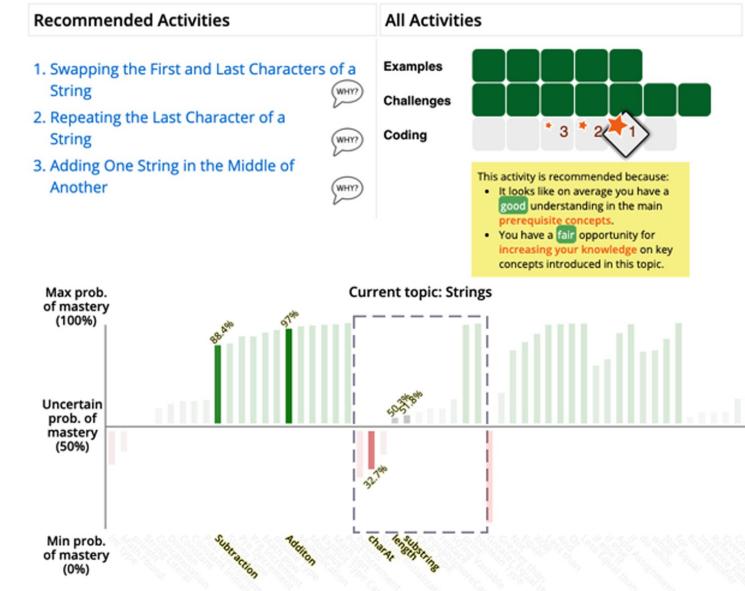
X-Recommendation

Novelty

Operationalized OLM: explain the concept-level mastery estimation to learners as support for the recommended activities

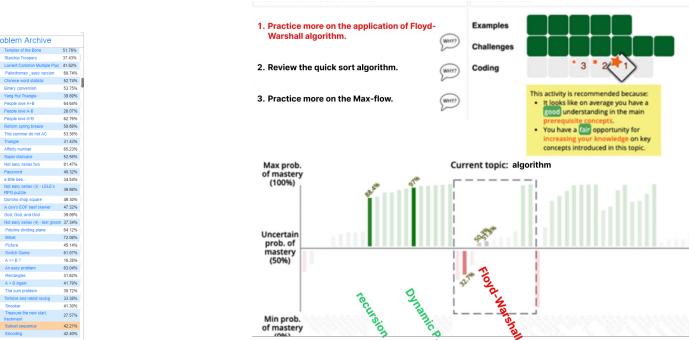
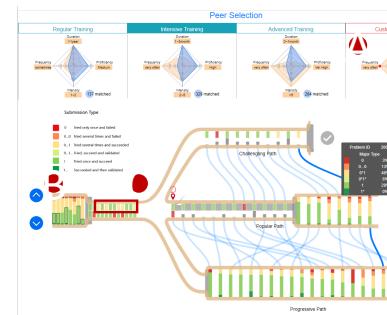
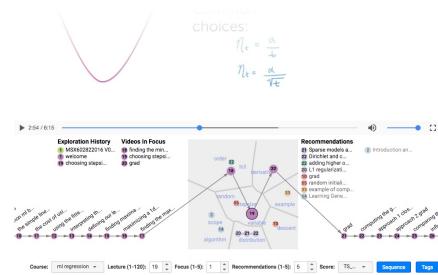
Limitation

Model selection: more advanced model for learner modelling



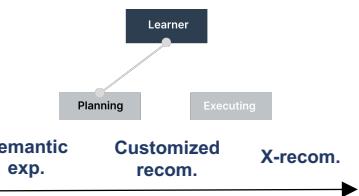
Barria-Pineda, J., Akhuseyinoglu, K., Želem-Čelap, S., Brusilovsky, P., Milicevic, A. K., & Ivanovic, M. (2021, June). Explainable recommendations in a personalized programming practice system. In *International conference on artificial intelligence in education* (pp. 64-76). Cham: Springer International Publishing.

Planning: summary



Learners use interactive VA to do planning by explore and explain learning content recommendations.

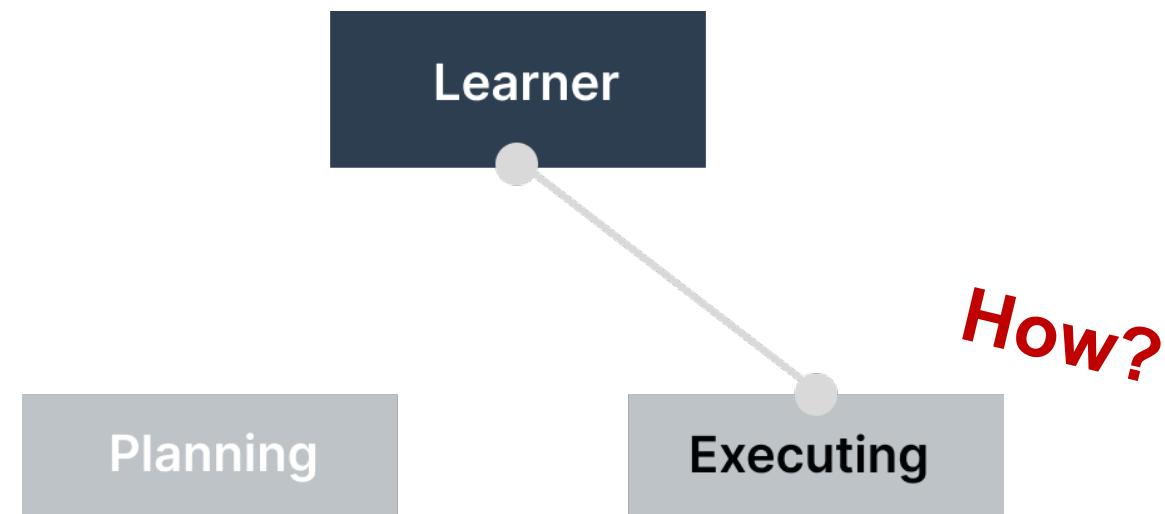
Trends: in-depth personal data analysis & pedagogical theory operationalization.



Executing

Definition: Carryout learning activities with **Intelligent Tutoring Systems**

Computer-based systems to provide **personalized instruction or feedback**



VanLehn, K. (2011). The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems. *Educational psychologist*, 46(4), 197-221.

Adaptive feedback

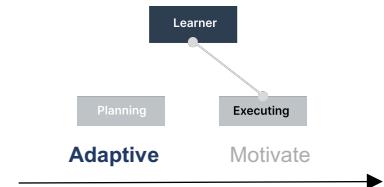
Research Question

How to improve argumentation (higher order thinking skill)?

Pedagogical theory

It is of great importance for the individual student to receive **continuous feedback** throughout their learning journey to learn high order thinking skills [1].

[1] Paul Black and Dylan Wiliam. 2009. Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability* 21, 1 (2009), 5–31.



Wambsganss, T., Niklaus, C., Cetto, M., Söllner, M., Handschuh, S., & Leimeister, J. M. (2020, April). AL: An adaptive learning support system for argumentation skills. In *Proceedings of the 2020 CHI conference on human factors in computing systems* (pp. 1-14).

Adaptive feedback

Methods

Provide **continuous feedback** to individual learners by argument mining algorithms and visualizing the **argumentation structure** of a text & indicate missing.

Novelty

First intelligent feedback learning tool for high order skills.

Limitation

Sentence structure decomposition as the only source of feedback, which can be more informative.

The screenshot displays the AL adaptive learning support system interface. At the top, there's a navigation bar with icons for Home, Write, and Progress. Below it is a 'Text editor' section labeled F1, containing a text input field with German text about a household app. A button 'Click on claims' is present. To the right, there are buttons for '# Words: 236', 'Analyze' (labeled F3), and 'Explanation' (labeled F2). Below the text editor is a 'Your personal argumentation learning dashboard' section labeled F4, featuring a pie chart for 'Argumentative [95%]' and 'Non-Argumentative [5%]'. It also includes a bar chart for 'Readability', 'Coherence', and 'Persuasiveness'. A network diagram labeled F5 shows the argumentation structure with nodes and support edges. A 'Detailed feedback on the structure of your claims' section labeled F6 contains several yellow callout boxes with feedback text. At the bottom, a progress bar indicates skill levels from Novice to Expert, with 'Advanced' selected. A message at the bottom right states 'Your argumentation improved by 24 % compared to the last exercise.' A legend at the bottom right maps colors to skill levels: blue for Novice, light blue for Advanced, grey for Competent, light green for Proficient, and dark green for Expert. A large arrow on the right points from 'Learner' through 'Planning' and 'Executing' to 'Motivate'.

Wambsganss, T., Niklaus, C., Cetto, M., Söllner, M., Handschuh, S., & Leimeister, J. M. (2020, April). AL: An adaptive learning support system for argumentation skills. In *Proceedings of the 2020 CHI conference on human factors in computing systems* (pp. 1-14).

Adaptive feedback

Research Question

How to help learner master different **voice modulation** skills in public speaking (pitch, pause, volume, speed)?

Pedagogical theory

Voice modulation skills play key role in the domain of public speaking [1].

[1] Eva Strangert. 2005. Prosody in public speech: analyses of a news announcement and a political interview. In Proceedings of the European Conference on Speech Communication and Technology. 3401–3404.



Wang, X., Zeng, H., Wang, Y., Wu, A., Sun, Z., Ma, X., & Qu, H. (2020, April). Voicecoach: Interactive evidence-based training for voice modulation skills in public speaking. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (pp. 1-12).

Adaptive feedback

Methods

Example-based recommendation with adaptive & quantitative visual feedbacks as training materials.

Limitation

Examples base training without considering context and topic info.



Wang, X., Zeng, H., Wang, Y., Wu, A., Sun, Z., Ma, X., & Qu, H. (2020, April). Voicecoach: Interactive evidence-based training for voice modulation skills in public speaking. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (pp. 1-12).

Adaptive feedback

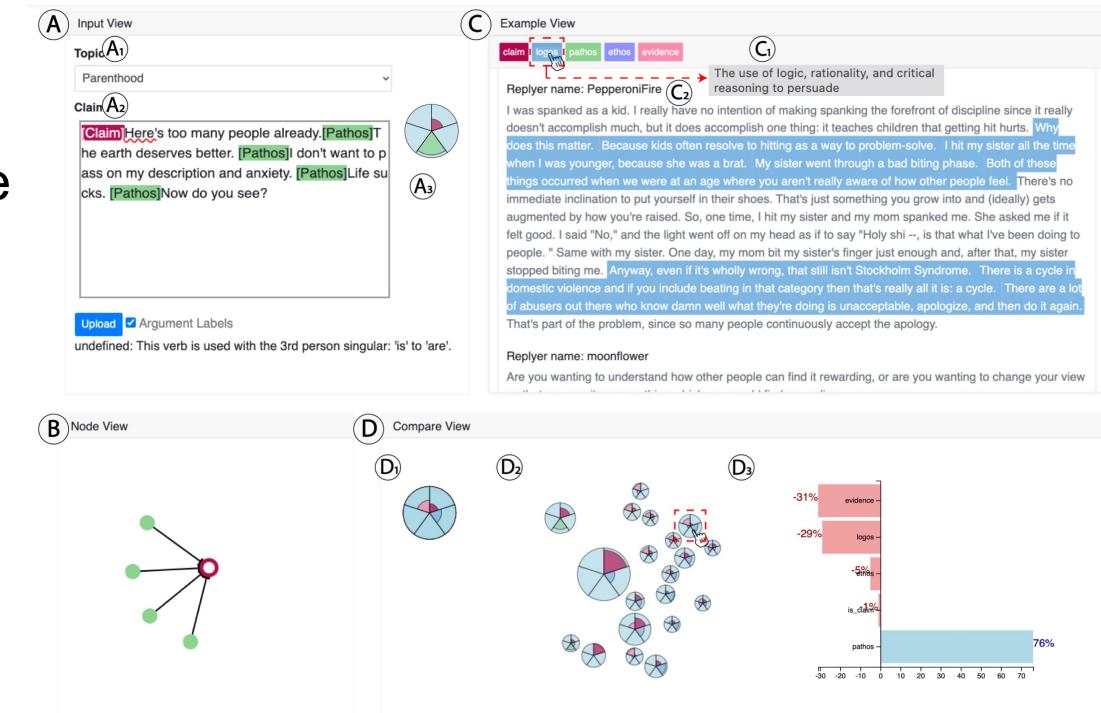
Research Question

How to practice persuasive arguments in online discussion via writing ?

Pedagogical theory

Constructing arguments in adherence to **persuasive strategies** can enhance the effectiveness of these arguments [1].

[1] Orji, R., Vassileva, J., & Mandryk, R. L. (2014). Modeling the efficacy of persuasive strategies for different gamer types in serious games for health. *User Modeling and User-Adapted Interaction*, 24, 453-498.



Xia, M., Zhu, Q., Wang, X., Nie, F., Qu, H., & Ma, X. (2022). Persua: A visual interactive system to enhance the persuasiveness of arguments in online discussion. *Proceedings of the ACM on Human-Computer Interaction*, 6(CSCW2), 1-30.

Adaptive feedback

Methods

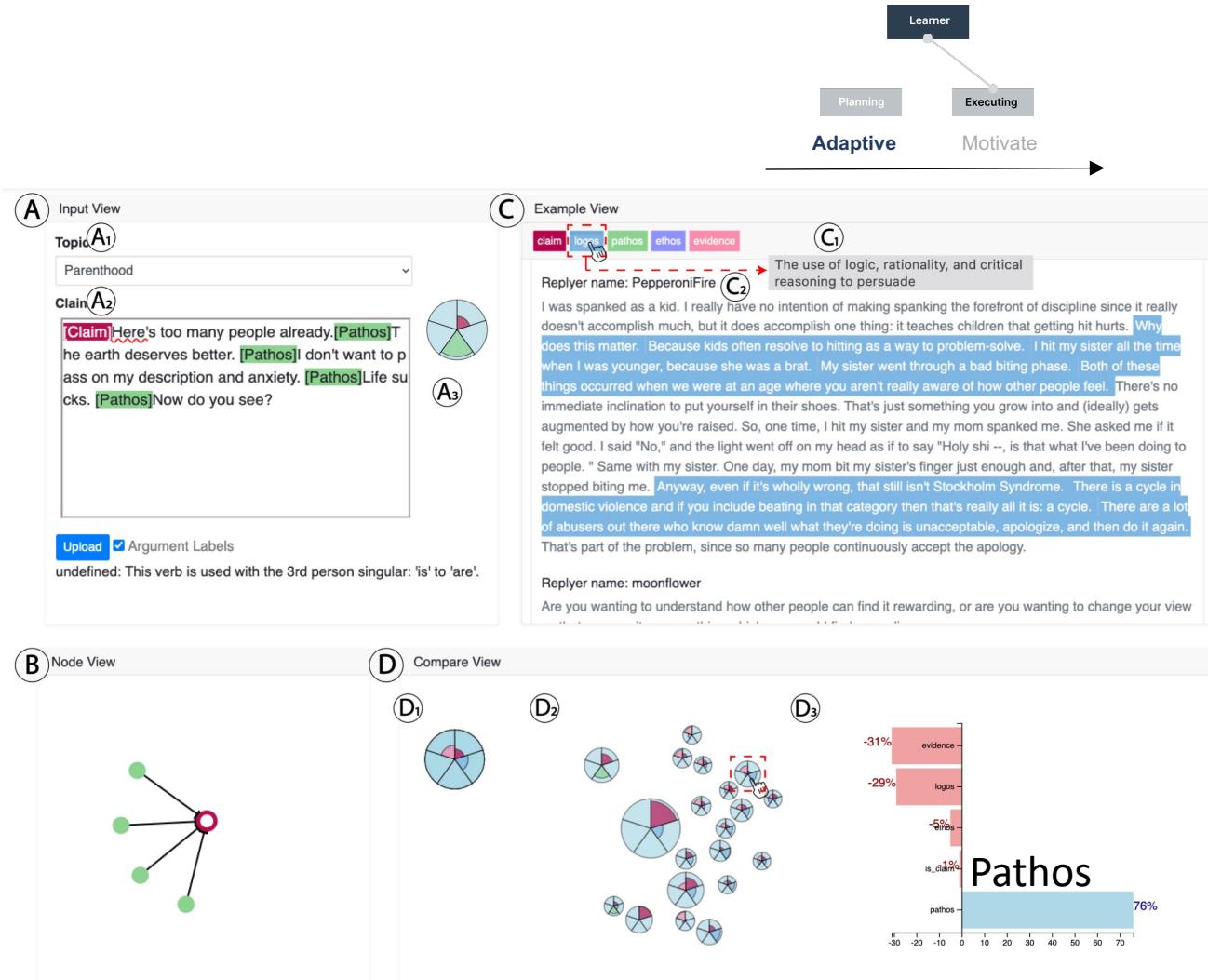
Summarize fine-grained **persuasive strategies**.
Strategies mining and example-based feedback.

Novelty

Taxonomy of argument components. Embed persuasive strategies into feedback design.

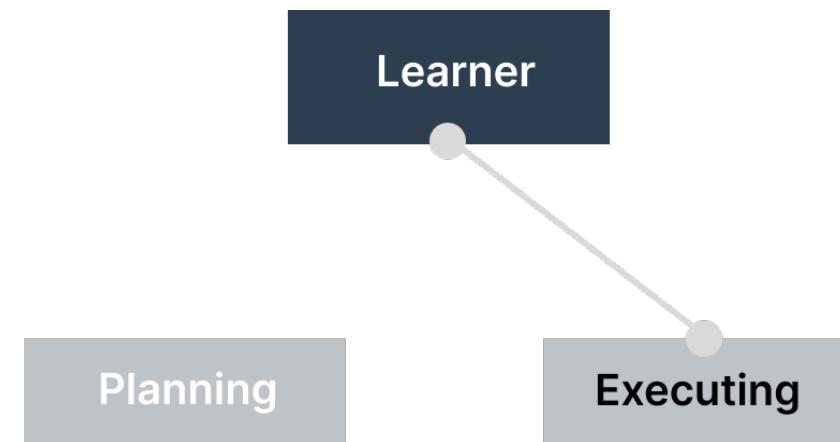
Limitation

Personality & demographic analysis still lack.



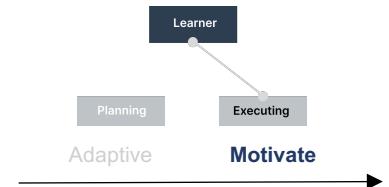
Xia, M., Zhu, Q., Wang, X., Nie, F., Qu, H., & Ma, X. (2022). Persua: A visual interactive system to enhance the persuasiveness of arguments in online discussion. *Proceedings of the ACM on Human-Computer Interaction*, 6(CSCW2), 1-30.

Executing: What's more



Beyond providing **increasingly theory-based, informative adaptive feedback**, what additional capabilities does interactive visual analytics offer to learners during the execution of personalized learning?

Motivate learning



Use interactive visualization to motivate multiple types of self learning!

Levels of agreement between your responses and your confidence

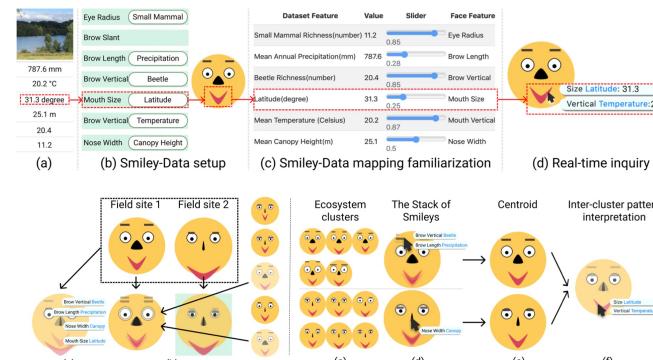
Full agreement	known	misconceptions	unknown	not covered
High agreement	known	misconceptions	unknown	not covered
Medium agreement	known	misconceptions	unknown	not covered
Low agreement	known	misconceptions	unknown	not covered

System model

- The Algebra of Complex Numbers
- Point Representation of Complex Numbers MISCONCEPTIONS
- Vectors and polar Forms

(Al-Shanfari et al., AIED 17)

Motivate students to address their personal weaknesses by **visualizing the disparity** between their assessed knowledge level and their self-confidence.



Motivate K-12 students to **investigate** their personal **scientific hypotheses** through interactive visualization.

Student Actions > Space: Presentation Skills > Watch Video: TUTORIAL 2: How to open and close presentations?

Watch video: TUTORIAL 2: How to open and close presentations?

Presentation lesson from Mark Powell, Cambridge University Press ELT, 7 min.

Well done!

You made your first self-reflective comment for this video! Self-reflections help you improve your soft skills.

Your previous comments

- 00:14 helpful Aspect I like this point
- 00:15 Encourage More Try to execute more on the video in your next comment. For example: Telling a short interesting anecdote to begin a presentation gets the audience interested, a very good idea
- 00:19 ...
- 00:27 the first and last three minutes are the most important, so beginning and closing are the most important part Aspect I like the point
- 02:28 ...
- 05:51 starting with shocking stats or an example could attract the audience from the beginning Aspect I always do this in the past
- 05:51 ...
- 05:56 I am good at starting the presentation by telling a story that clarifies what is the problem. Aspect I am rather good at this
- 05:58 Click on the dialog icon to see the hint you received previously

Others commented

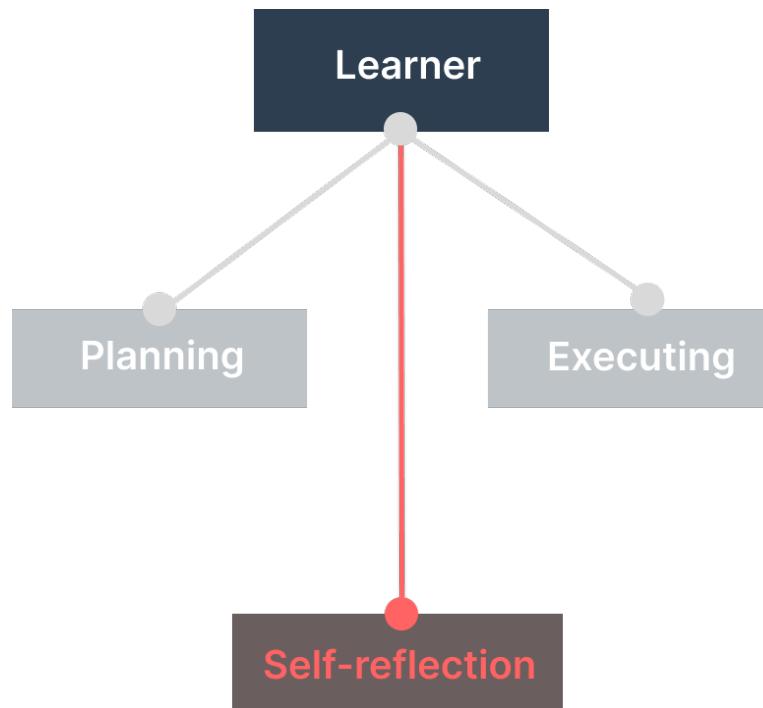
You commented:

Add comment

(Mohammadhassan et al., AIED 22)

Motivate students to **comment** on each-others' learning reviews and receive feedbacks via interactive visualization.

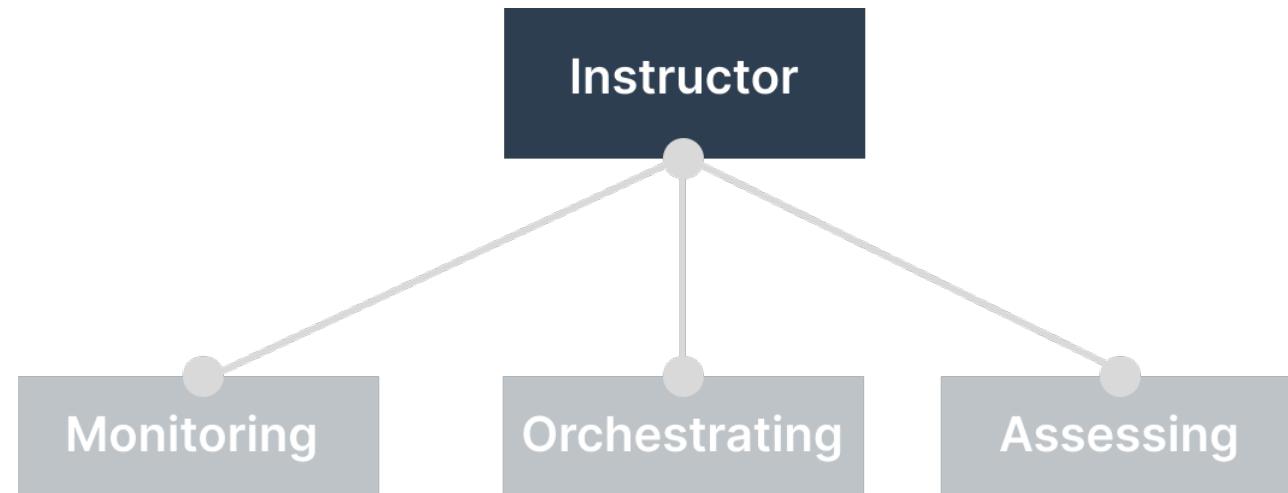
Summary for Learner



- To enhance personalized learning, learner mainly use interactive VA systems to **plan** learning path and receive adaptive feedback during learning activities **execution**.
- The trend is moving towards more **in-depth** personal data analysis and **informative** feedbacks with the basis of more **advanced** pedagogical theories.
- Still limited work focus on **learner's self-reflection**. It can be perfectly linked to some mature pedagogical theories.

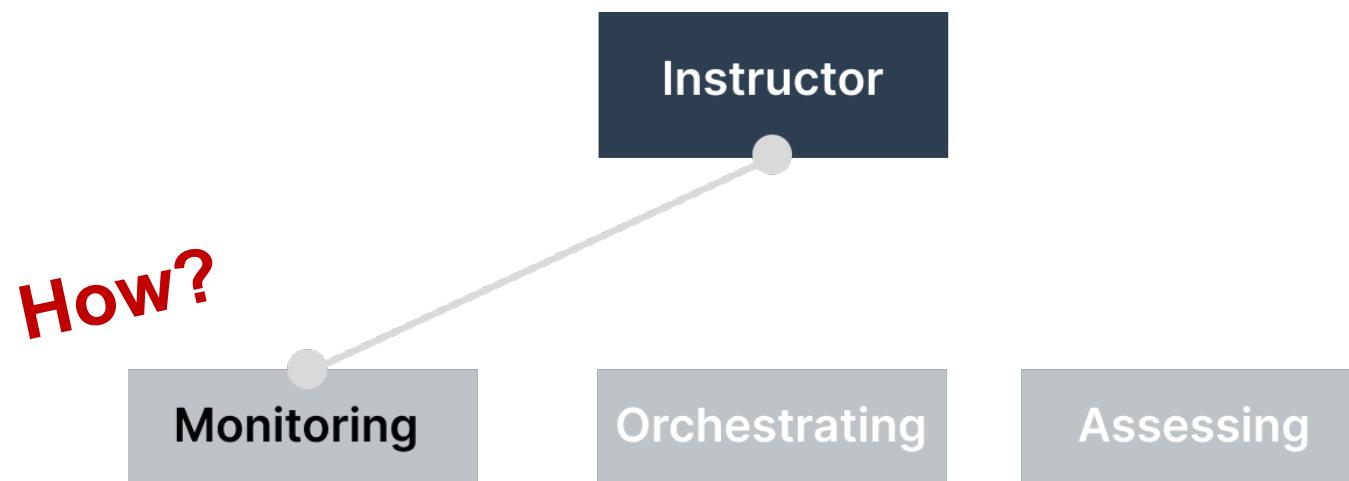
Instructor

Why do instructors use the VA systems to support personalized learning?



Monitoring

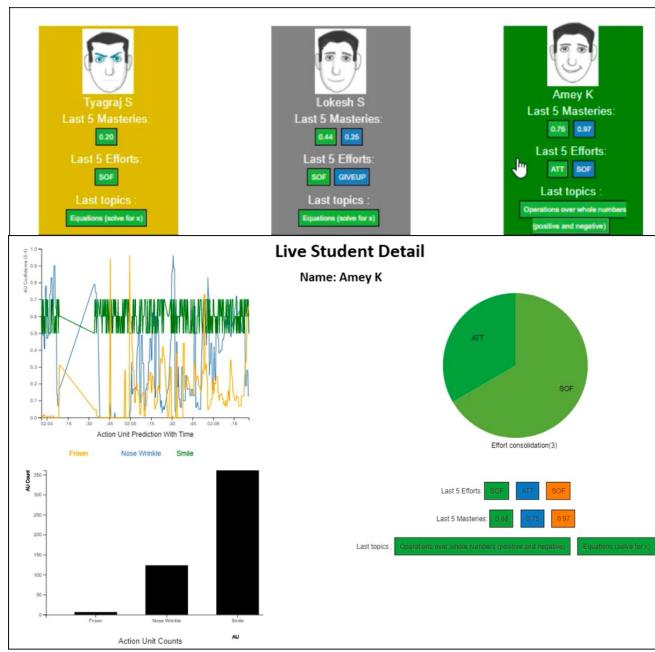
Definition: Instructors monitor learner data, deriving insights from their progress or status to prepare for necessary **real-time interventions**.



Srinivasa, K. G., Kurni, M., & Saritha, K. (2022). Harnessing the Power of AI to Education. In *Learning, Teaching, and Assessment Methods for Contemporary Learners: Pedagogy for the Digital Generation* (pp. 311-342). Singapore: Springer Nature Singapore.

Monitor learner status

Monitor engagement level or emotional status as reference for instructor intervention or class pace adjustments.

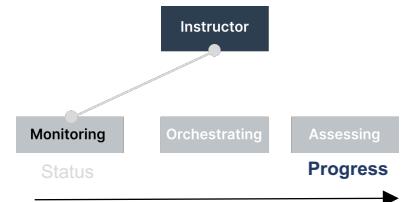


Engagement and affective states analysis from **facial expressions**, personalized but no intervention

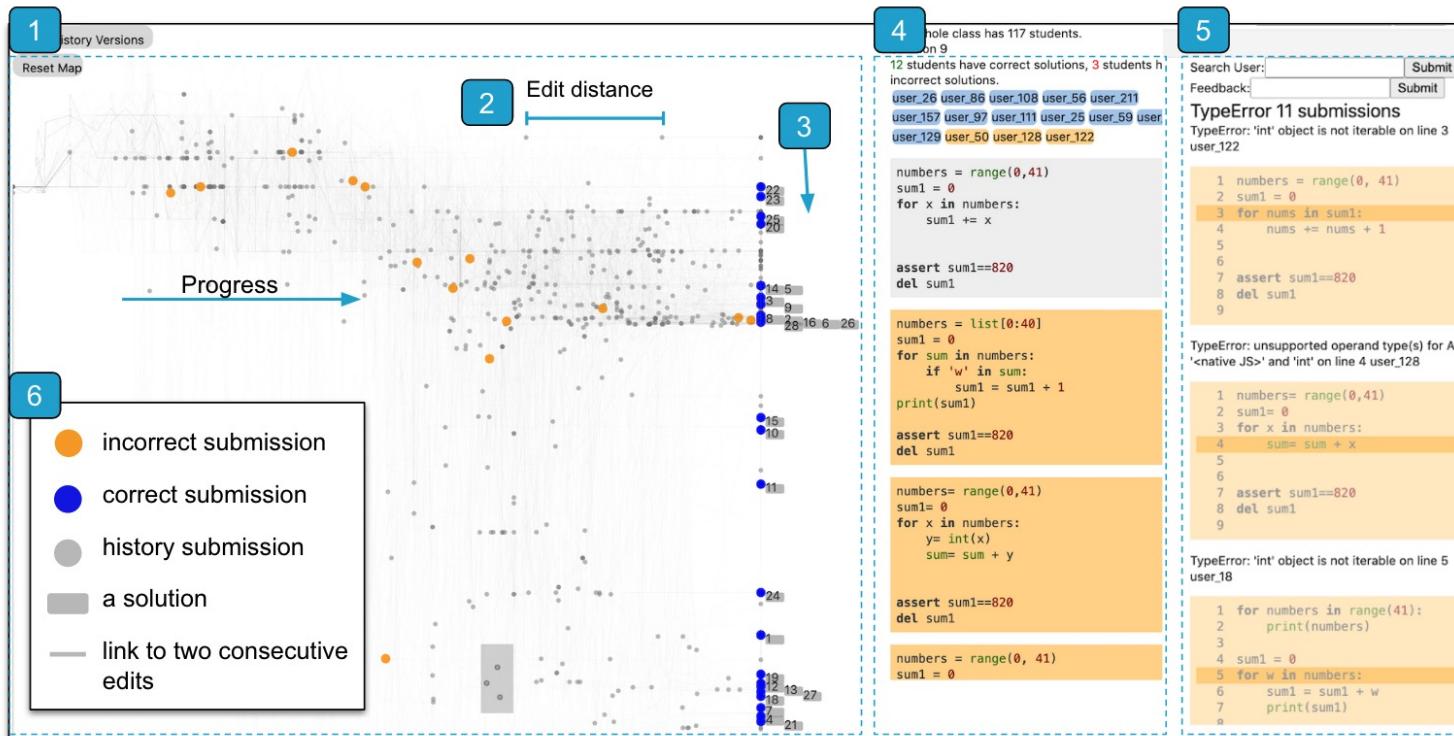


Engagement, confusion, Gaze and emotion analysis from **facial expression**, sacrifice personalization due to data privacy protection.

Monitor learning progress



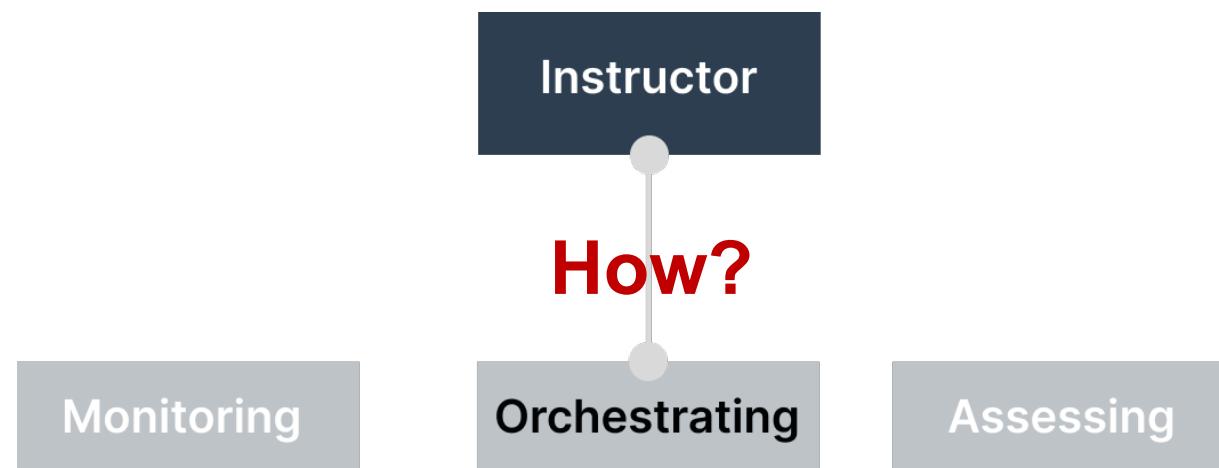
Monitor real-time problem-solving progress as reference for intervention.



Monitor each learners' real-time code progress and edit distance towards potential solutions.

Orchestrating

Definition: Instructors conduct real-time learning **activities management** of multiple social planes (e.g., individuals, groups, and classes)



Dillenbourg, P., Prieto, L. P., & Olsen, J. K. (2018). Classroom orchestration. *International handbook of the learning sciences*, 180-190.

Learning Task Distribution

Domain Problem

Instructors **distribute** students into collaborative learning groups to discuss and solve problems.

Pedagogical theory

Promoting **collaborative learning** between learners is demonstrated to be effective on promoting personalized learning skills [1].

The screenshot shows a digital learning environment. At the top, there's a navigation bar with tabs like ACTIVITY, ORGANIZE, REVIEW, MY SHEET, and buttons for OPEN ENROLLMENT, TALK, PROJECT, +STUDENT, and +GROUP. Below the navigation, there's a list of students: harold, jen, and sabrina. To their right, three groups are formed: GROUP 1 (steve, robert), GROUP 2 (tom, marcello), and GROUP 3 (holly, joe). In the bottom half of the screen, there's a workspace with several mathematical expressions and logic gates. A tooltip for the expression $f(x) = O(g(x))$ is displayed, stating: "Annotations: $f(x) = O(g(x))$ is defined as: if there exists a positive real number M and a real number x_0 s.t. $|f(x)| \leq M|g(x)|$ for all $x \geq x_0$ ". The workspace also contains logic gates labeled False and True, and other mathematical expressions like $n \log(n) = O(n^2)$ and $n^2 \log(n) = O(n^3)$.

Cheema, S., et al.: Electronic posters to support formative assessment. In: CHI EA Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, pp. 1159–1164. ACM (2016)

[1]Abdelaziz, H. A., & Al-Ali, A. (2020). Promoting personalized learning skills: The impact of collaborative learning (a case study on the general Directorate of residency and foreigners affairs in Dubai). *International Journal of Learning, Teaching and Educational Research*, 19(2), 163-187.

Learning Task Distribution

Data

Students' online status &
Students' learning stage (Real-time tabular)

Encoding

Color scheme to encode:

learner's online status (A: synced/non-synced/absent)
learning stage (B: working on/passed the question)

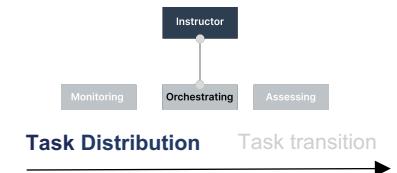
Algorithm: None

The screenshot shows a digital learning environment with the following features:

- Top Bar:** Includes tabs for ACTIVITY, ORGANIZE, REVIEW, MY SHEET, and a class selection dropdown (class1). It also has links for OPEN ENROLLMENT, TALK, PROJECT, +STUDENT, and +GROUP.
- Student Status:** A list of students (harold, jen, sabrina) with their online status indicated by color: green for harold and jen, and orange for sabrina.
- Grouping:** Students are grouped into three groups: GROUP 1 (steve, robert), GROUP 2 (tom, marcello), and GROUP 3 (holly, joe).
- Annotations:** A callout labeled A points to the student status area, and another labeled B points to a learning stage indicator. Below these, there is a mathematical annotation about Big O notation: $f(x) = O(g(x))$ is defined as: if there exists a positive real number M and a real number x_0 s.t. $|f(x)| \leq M|g(x)|$ for all $x \geq x_0$.
- Learning Stage Indicators:** In the bottom section, there are tables for different questions. Each table has three columns: a formula, a "False" button, and a "True" button. The "True" button is highlighted in blue, indicating the learning stage (B).

Cheema, S., et al.: Electronic posters to support formative assessment. In: CHI EA Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, pp. 1159–1164. ACM (2016)

Learning Task Distribution

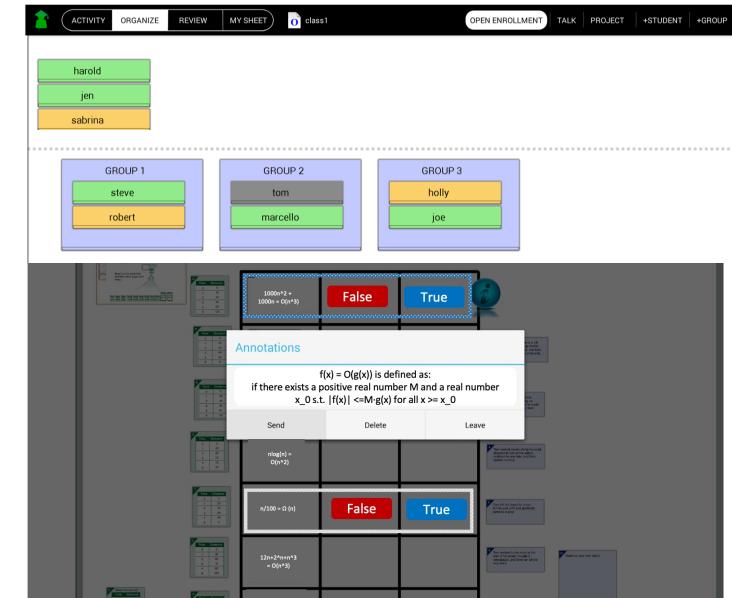


Novelty

First system to help instructor conduct collaborative learning and crafting learning experience.

Limitation

Limited analysis on students' status and progress.



Cheema, S., et al.: Electronic posters to support formative assessment. In: CHI EA Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, pp. 1159–1164. ACM (2016)

Learning Task Transition

Domain Problem

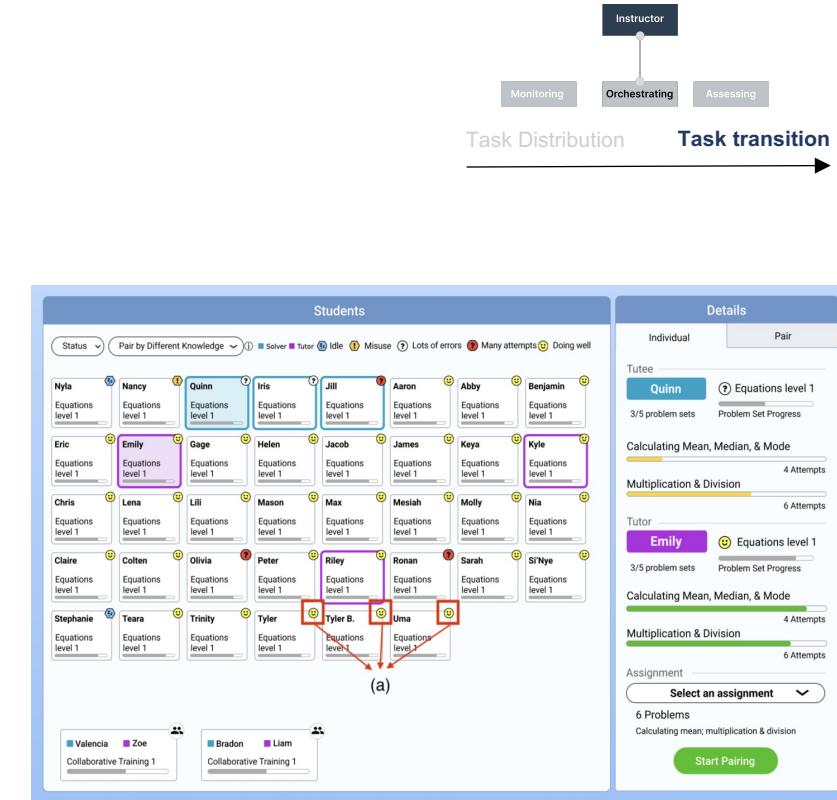
Instructors orchestrate the **dynamic transitions** of students' individual and collaborative learning.

When to choose **whom** to pair up, **role** of each, and **what** collaborative assignment they should work on.

Pedagogical theory

Switching learners to learning activities most suitable for them yield better learning [1].

Transitions between individual/collaborative learning can leverage the complementary benefits of both [2].



Yang, K. B., Echeverria, V., Lu, Z., Mao, H., Holstein, K., Rummel, N., & Aleven, V. (2023, April). Pair-Up: Prototyping Human-AI Co-orchestration of Dynamic Transitions between Individual and Collaborative Learning in the Classroom. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (pp. 1-17).

[1] Haoran Xie, Hui-Chun Chu, Gwo-Jen Hwang, and Chun-Chieh Wang. 2019. Trends and development in technology-enhanced adaptive/personalized learning: A systematic review of journal publications from 2007 to 2017. *Computers & Education* 140 (06 2019), 1–16. <https://doi.org/10.1016/j.compedu.2019.103599>

[2] Pierre Dillenbourg and Patrick Jermann. 2010. Technology for Classroom Orchestration. Springer New York, New York, NY, 525–552. https://doi.org/10.1007/97814419-5716-0_26

Learning Task Transition

Data

Students' learning log data

Students' learning state data (Real-time tabular)

Encoding

Displays students in card format (A)

Icon encode learner status (B)

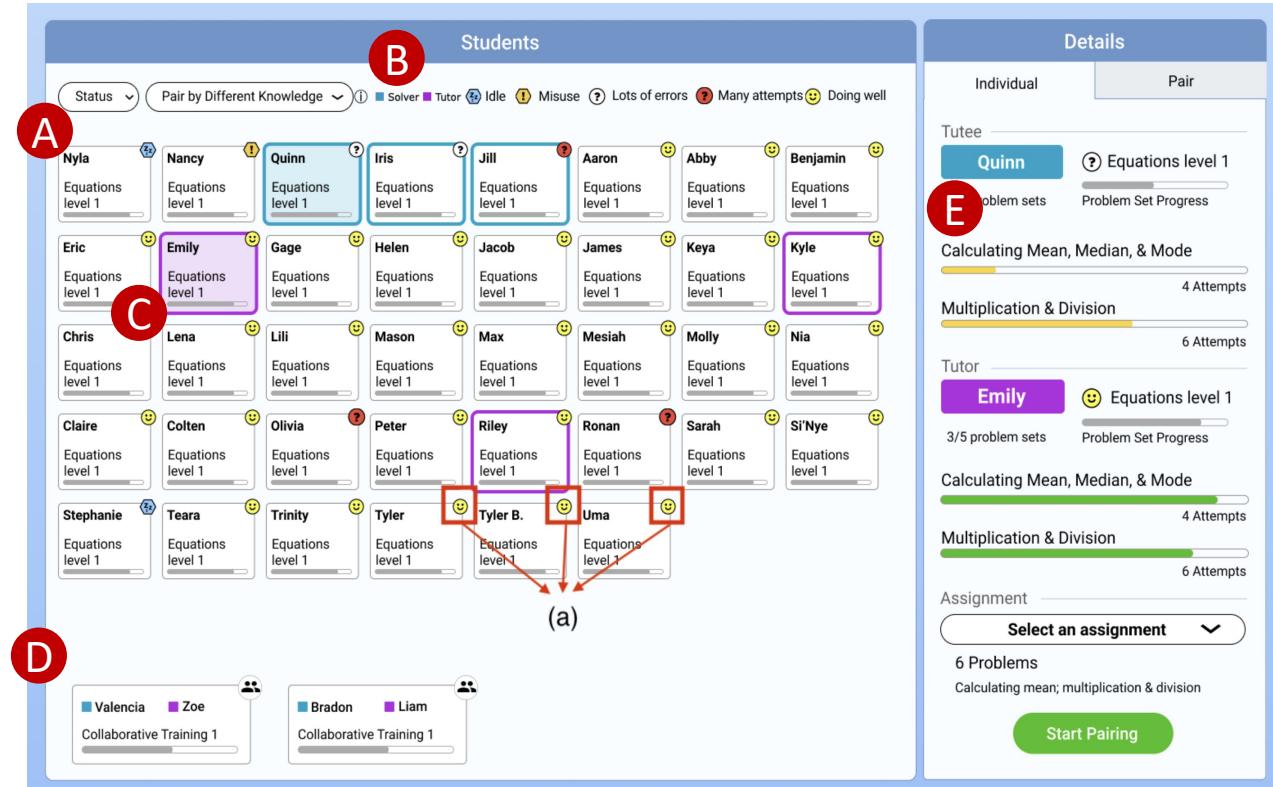
Color encode learner role (C: solver/tutor)

Bar (D) encode collaboration progress

Bar (E) encode knowledge mastery level

Algorithm

Bayesian Knowledge Tracing to model mastery of the knowledge.



Yang, K. B., Echeverria, V., Lu, Z., Mao, H., Holstein, K., Rummel, N., & Aleven, V. (2023, April). Pair-Up: Prototyping Human-AI Co-orchestration of Dynamic Transitions between Individual and Collaborative Learning in the Classroom. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (pp. 1-17).

Learning Task Transition

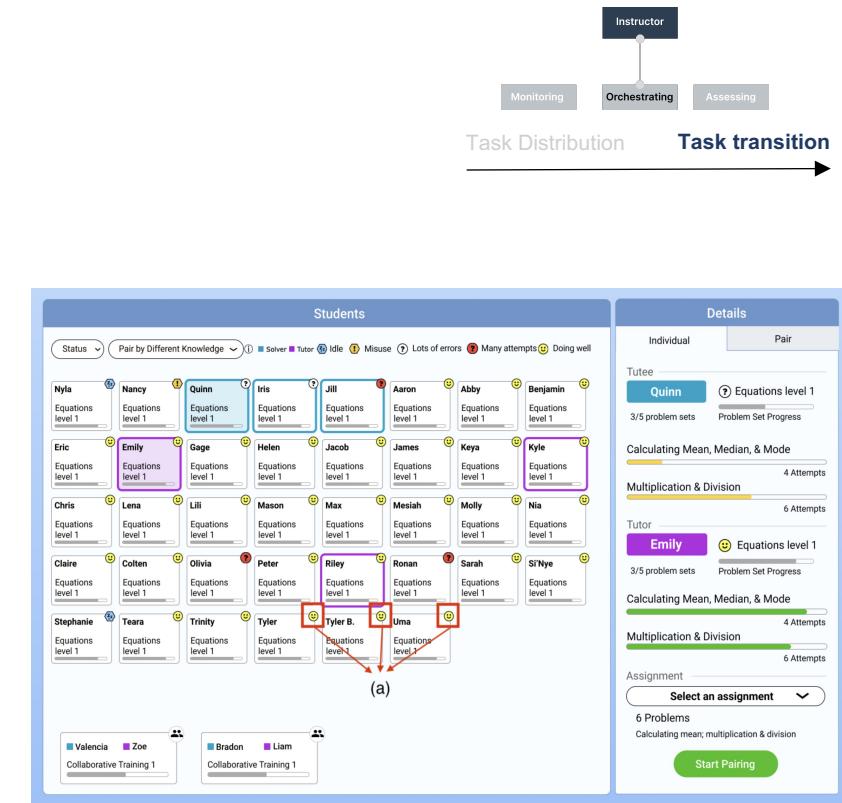
Novelty

Progressively implementation of advanced pedagogical theories.

Human-AI Collaborative Approach for students pair up.

Limitation

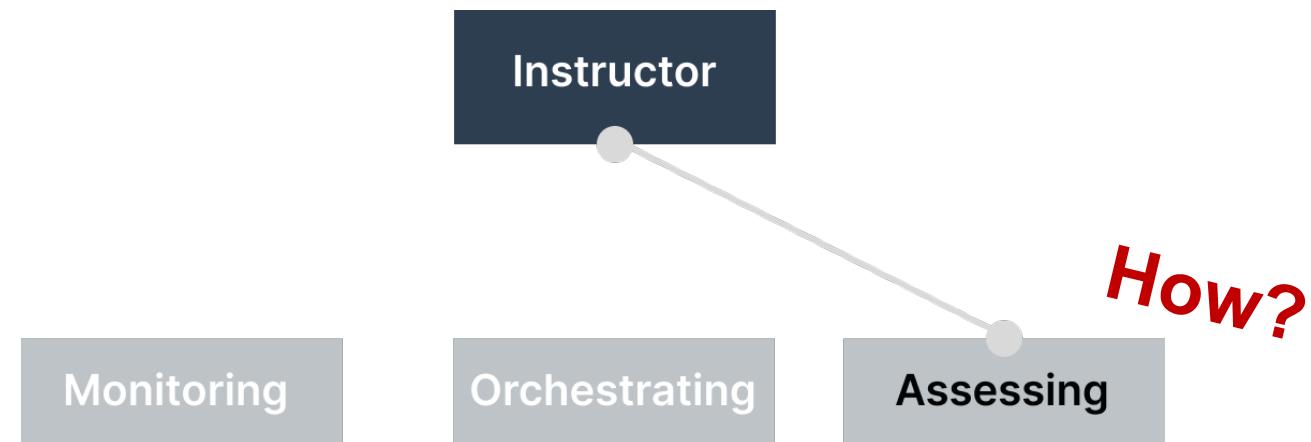
No **students' control** on learning activities (to be learner-centered).



Yang, K. B., Echeverria, V., Lu, Z., Mao, H., Holstein, K., Rummel, N., & Aleven, V. (2023, April). Pair-Up: Prototyping Human-AI Co-orchestration of Dynamic Transitions between Individual and Collaborative Learning in the Classroom. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (pp. 1-17).

Assessing

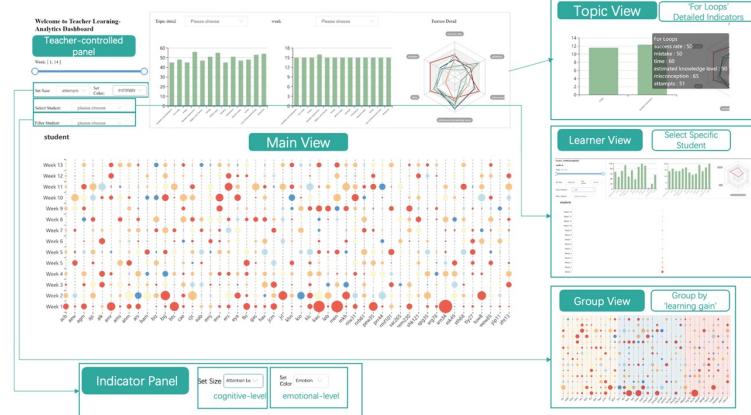
Focus: Assessment on learner and assessment on instructor for **reflection** and individualized feedback.



Beghetto, R. A. (2019). Large-scale assessments, personalized learning, and creativity: Paradoxes and possibilities. *ECNU Review of Education*, 2(3), 311-327.

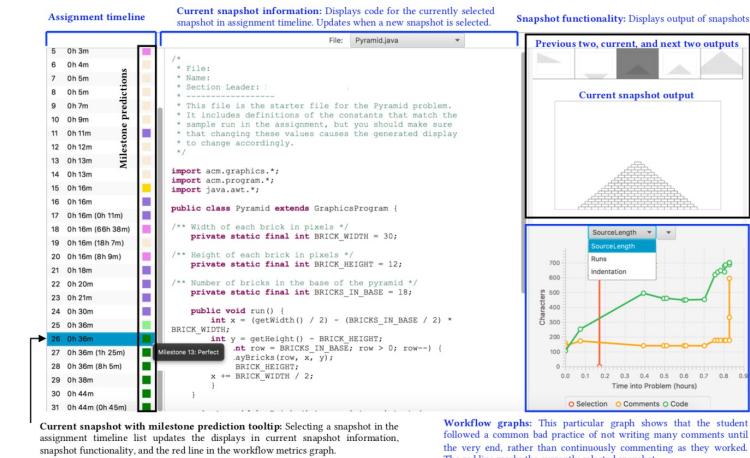
Learner Assessment

Conduct comprehensive learner assessment (knowledge-level, cognitive level, meta-cognitive level,...)



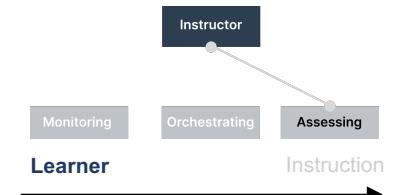
(Zhang et al., HCII 23)

Assess students' **learning behavior** and reasoning into their learning outcome.



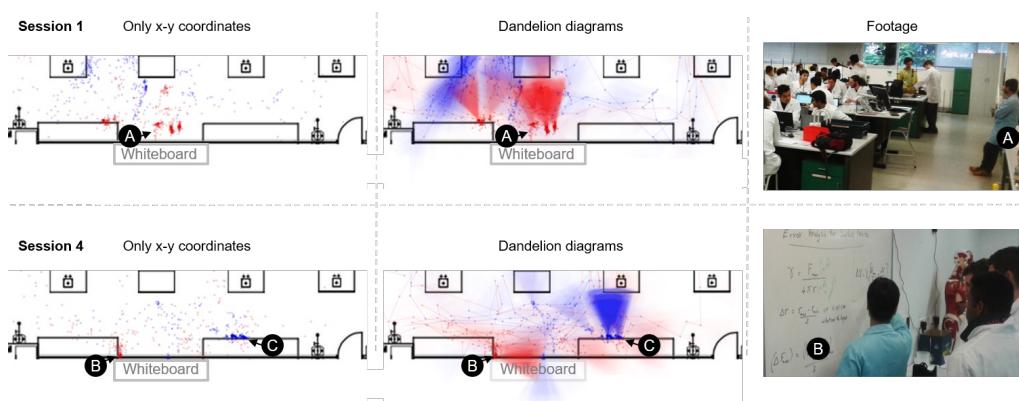
(Yan et al., SIGCSE 19)

Assess students' **problem-solving strategy** by review their problem-solving historical log data



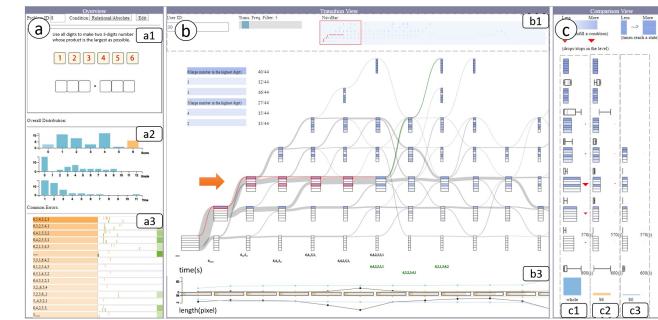
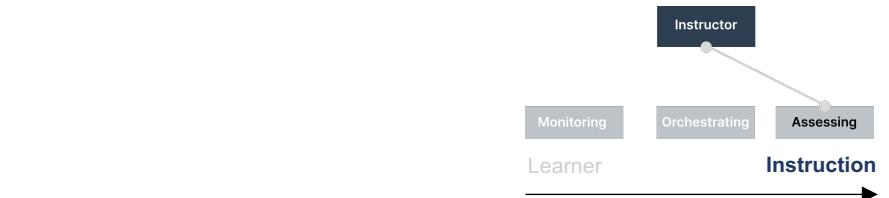
Instructor Assessment

Assess the question design and their in-class instruction strategy.



(Fernandez-Nieto et al., CHI 22)

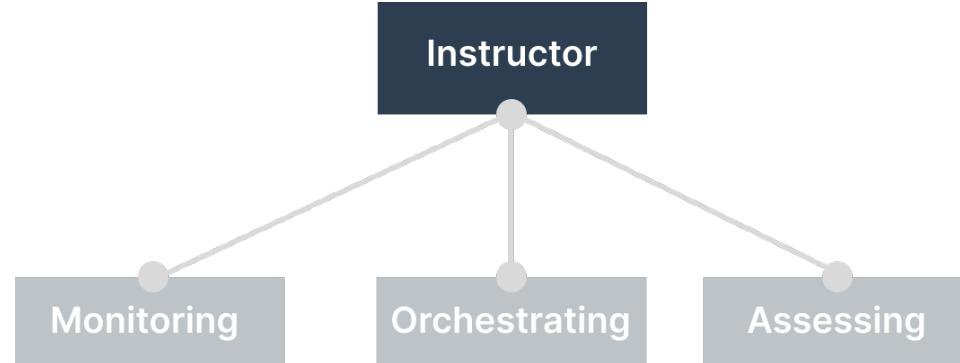
Visualize instructor' **classroom trajectory** to reflect on instruction strategy.



(Xia et al., TVCG 21)

Assess the matching between students' problem-solving logic with **questions' design** to refine the question design for specific learners' needs.

Instructor: summary



- To enhance personalized learning, instructors mainly use interactive VA systems to **monitor** their students, **orchestrate** learning activities and **assess** both students and themselves.
- The growing tendency is similar to the ones for learner side: pedagogical theorys, learner data analysis and student-centered design.

Outline

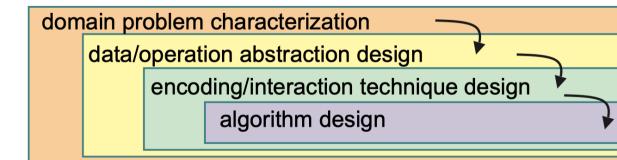
- Introduction
- Taxonomy
- Future Work
 - Four dimensions
- Take-home Message

Future Work

How can we **improve** the design of interactive visual analytics system to further promote more learner-centered personalized learning environment?

Borrow from the idea of the nested model for visualization design, we can think from the following perspectives:

- domain task to address
- data to use
- visualization representation and interaction
- algorithm to use



Munzner, T. (2009). A nested model for visualization design and validation. *IEEE transactions on visualization and computer graphics*, 15(6), 921-928.

Future Work

Data to Use

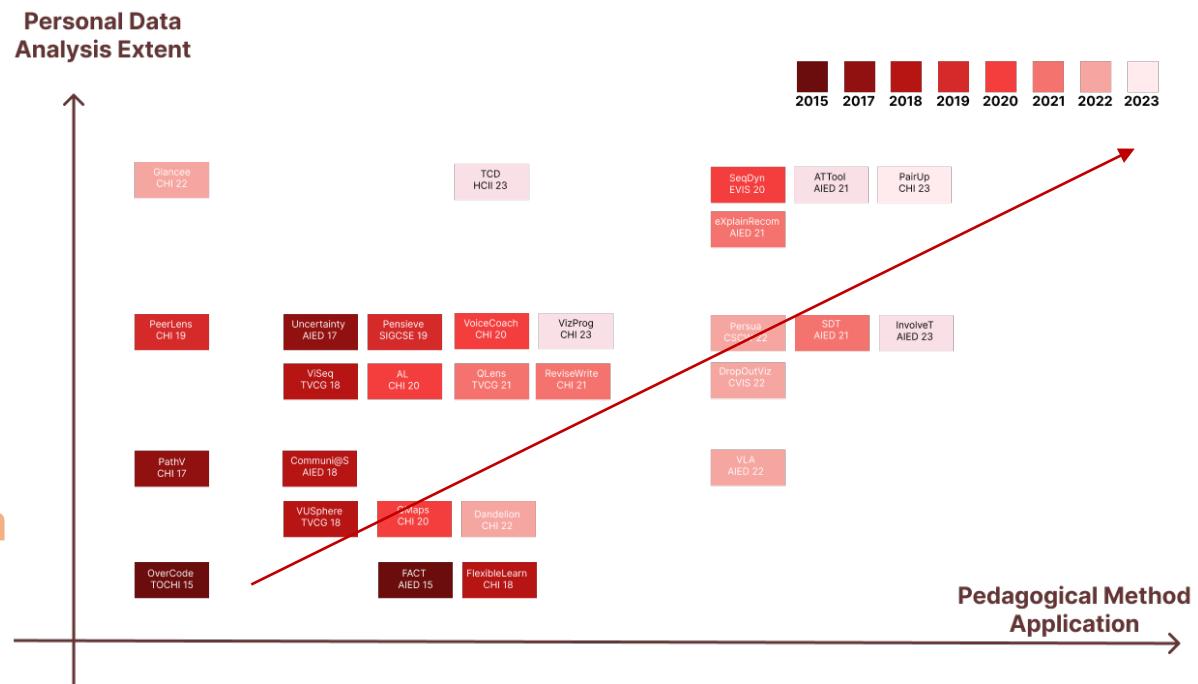
Go in-depth into
personal data utilization

e.g., personality,
demographic, multi-
modality analysis

Vis Representation

More learner-centered design

e.g., Balance the informativeness, Adaptiveness as well as user's cognitive load



Algorithm

Advanced Learner Model.
ChatGPT serve as AI TA to operationalize pedagogical methods:

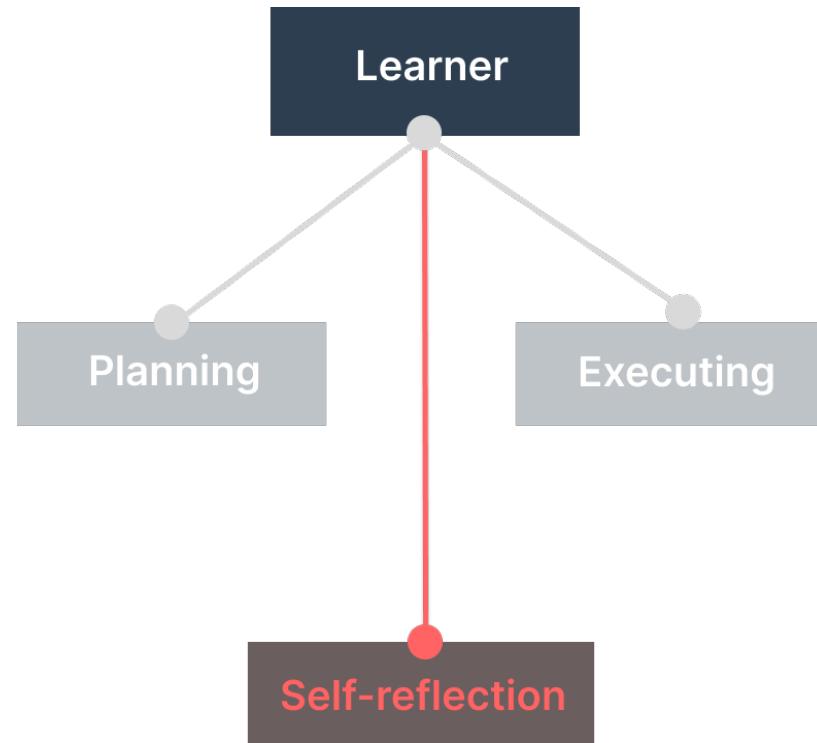
e.g., scaffolding for complex concept learning

Domain Task

VA as **medium** to operationalize personalized learning theories

e.g., specific training on personalized meta-cognitive abilities

Future Work



Short-term gap identified from taxonomy!

Outline

- Introduction
- Taxonomy
- Future Work
- Take-home Messages

Take-home Messages

- The needs for personalized learning in modern education
- Taxonomy: VA for personalized learning execution
 - Who, why, and how we use VA.
- Future Directions
 - Short-term
 - VA for learner's self reflection
 - Long-term directions
 - Operationalize personalized learning theories
 - In depth personal data analytics
 - Learner-centered design principles
 - Advance AI models

Thanks!

