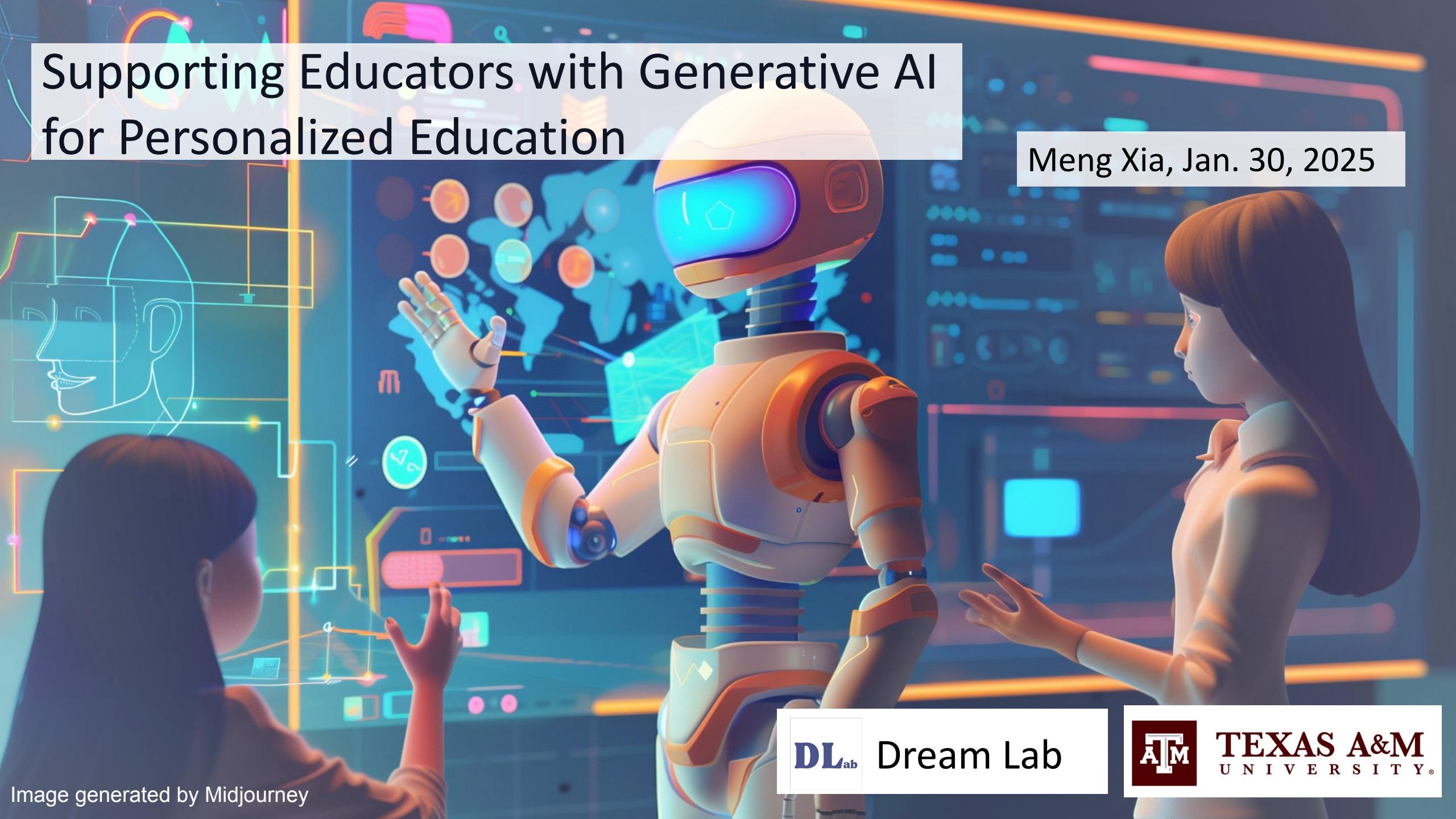


Supporting Educators with Generative AI for Personalized Education

Meng Xia, Jan. 30, 2025



Dream Lab



TEXAS A&M
UNIVERSITY®

Why personalization?



Non-cognitive

Motivation

(D'Mello, Lehman, Pekrun, & Graesser, 2014)

Self-regulation skills

(Aleven & Koedinger, 2002)

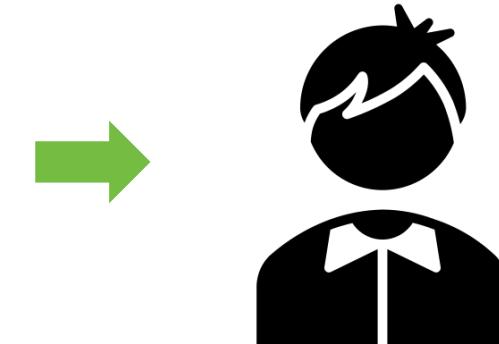
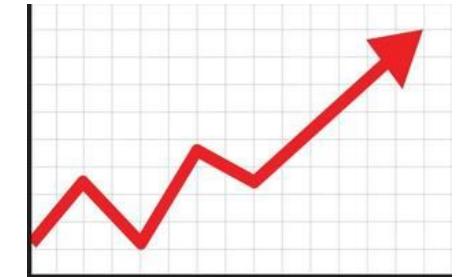
Cognitive

Knowledge

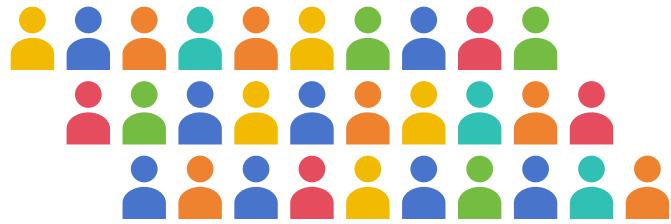
(Koedinger., Stamper, McLaughlin, & Nixon, 2013;)

Problem-solving strategies, errors

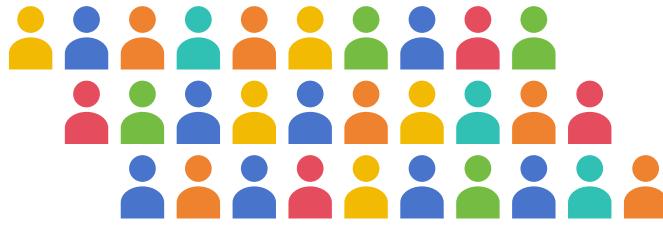
(Adams et al., 2014)



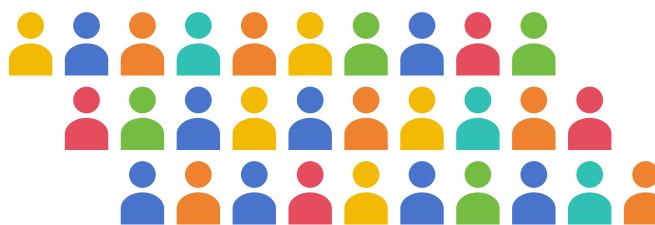
Personalization is a Foundational Education Challenge



- Large amount of students
- No enough qualified teachers

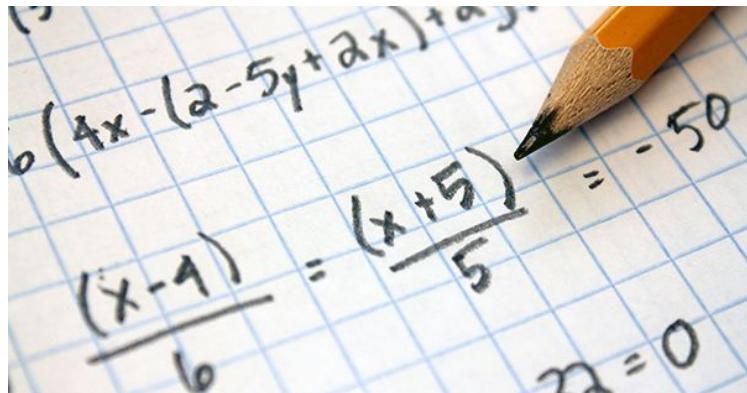


Personalization is a Foundational Education Challenge



- Large amount of students
- No enough qualified teachers
- Hard to analyze students' multimodality unstructured data
-

Generative AI is popular



Midjourney



Generative AI's Characteristics

- Understand unstructured data (e.g., text, image)
- Generate context-aware content

Unstructured Data



AI creates:



- Quizzes

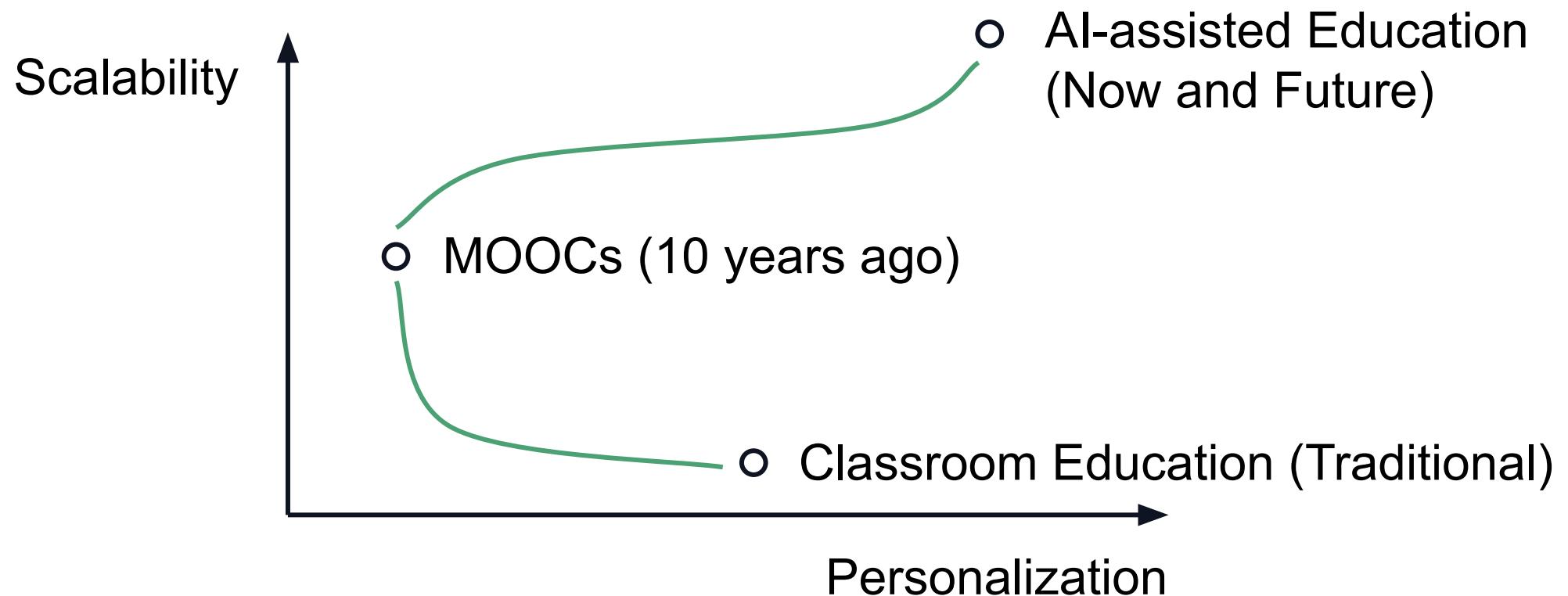


- Feedback

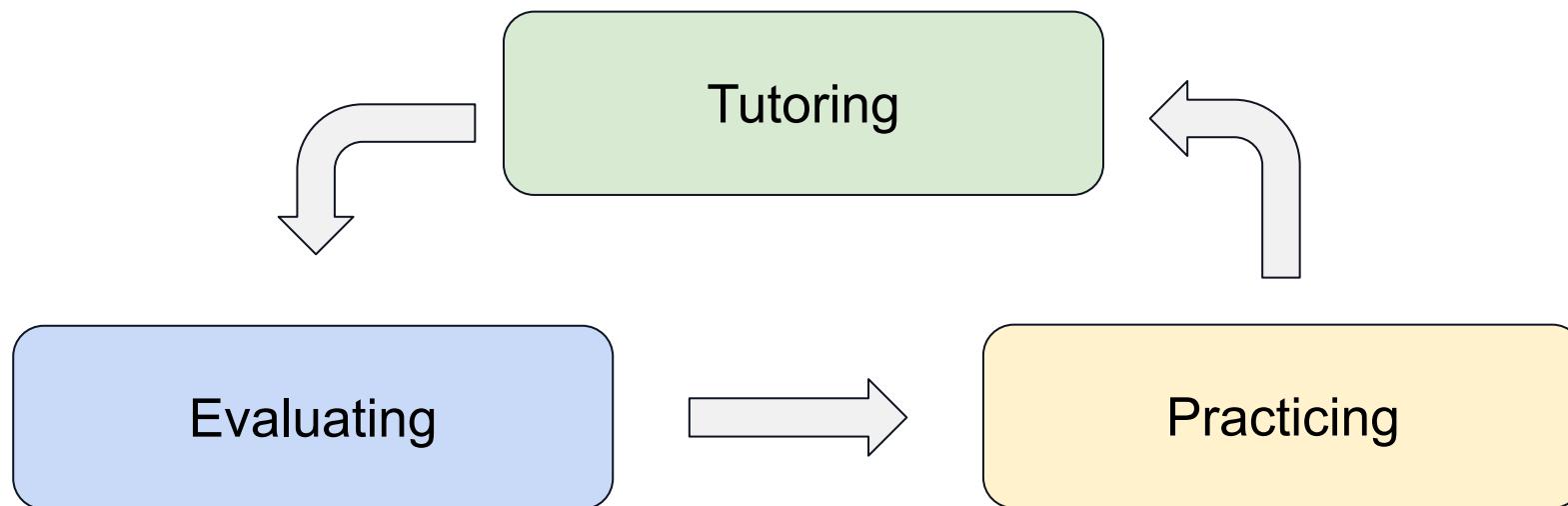


- Lessons

Vision for education: Personalization @ Scale

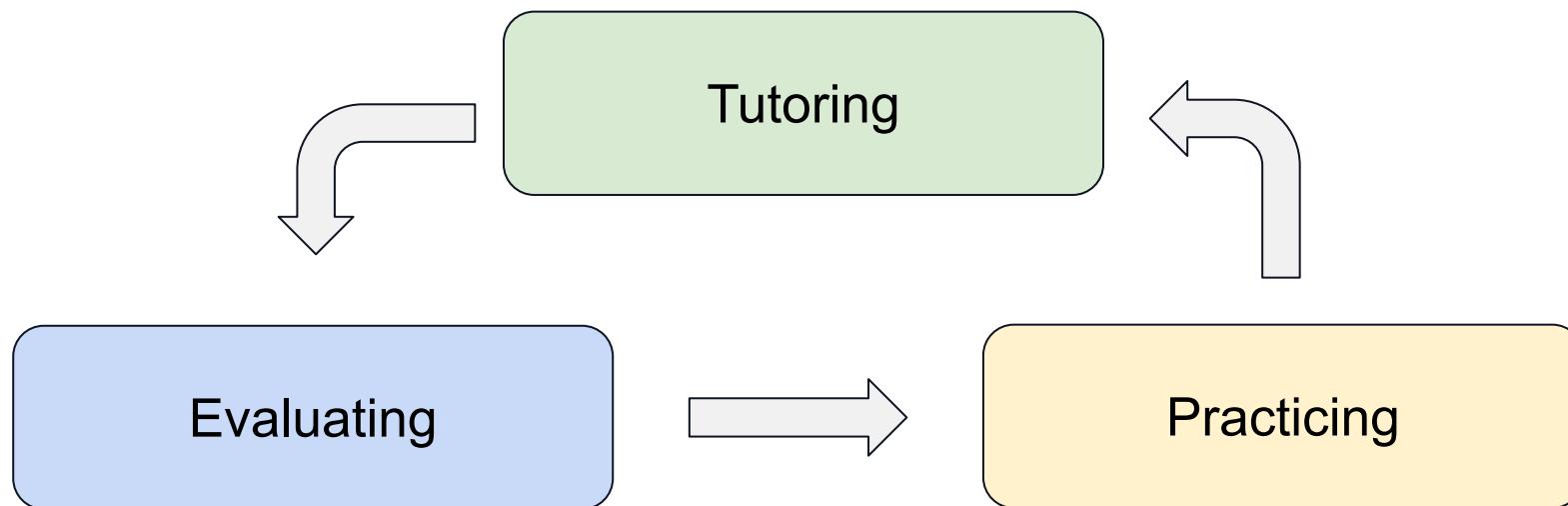


Educators' Tasks



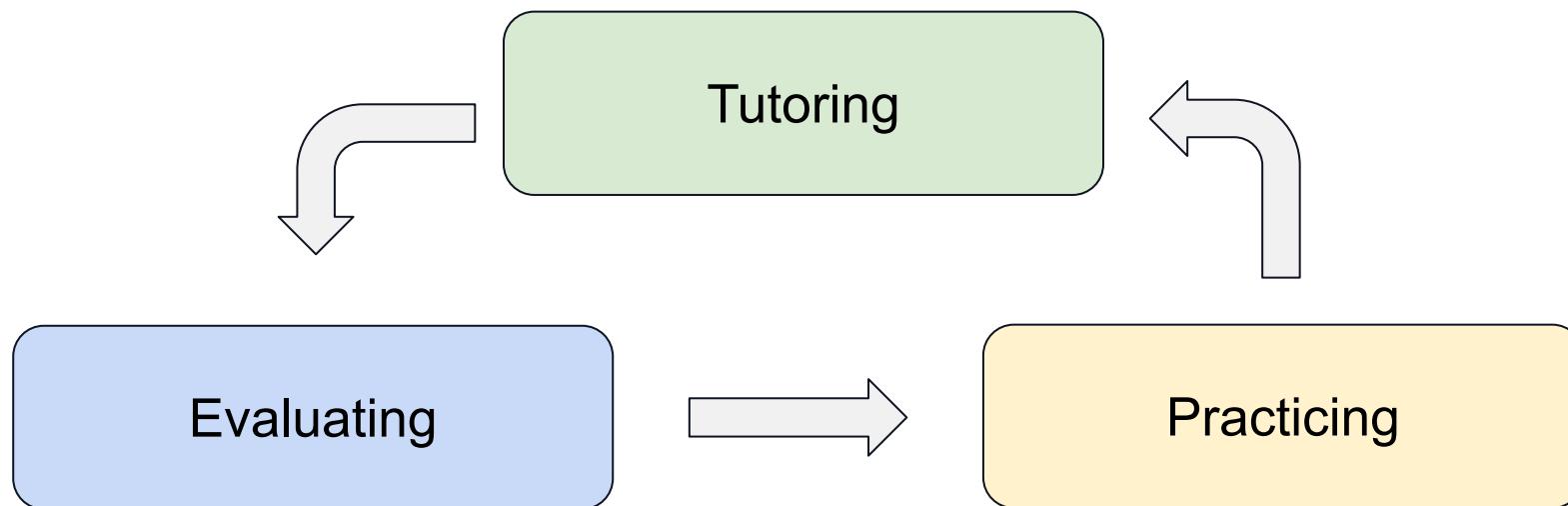
Generative AI's opportunities for Personalization

- Authoring personalized learning materials



Generative AI's opportunities for Personalization

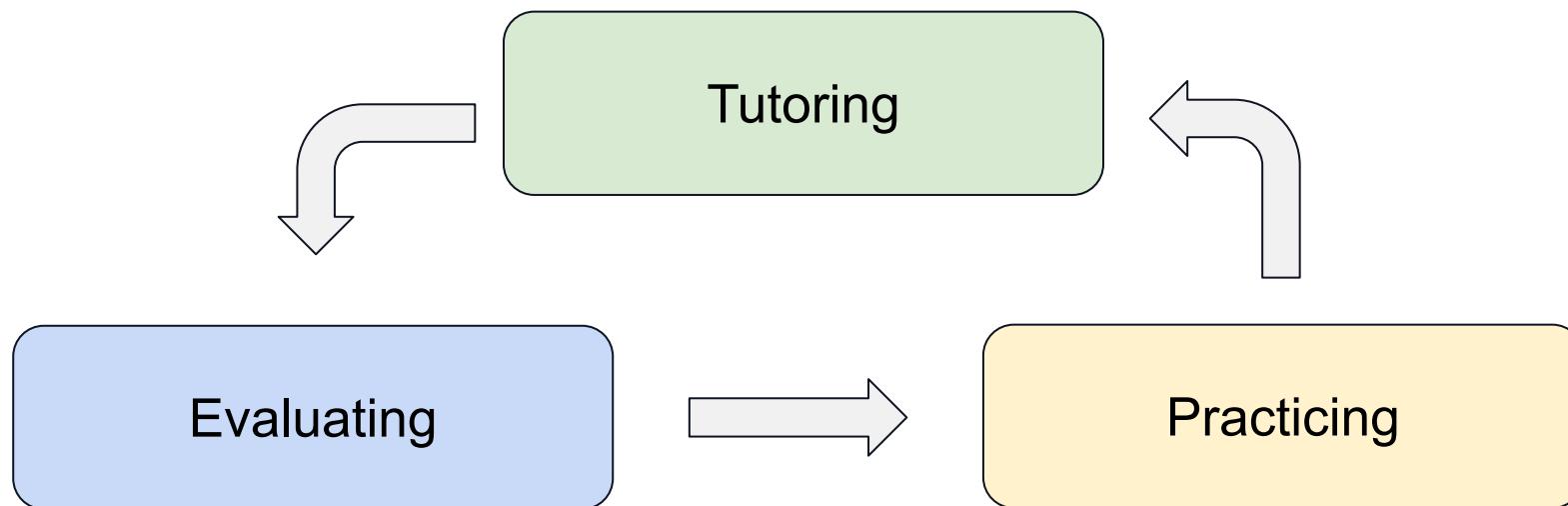
- Authoring personalized learning materials



- Evaluating student learning process

Generative AI's opportunities for Personalization

- Authoring personalized learning materials

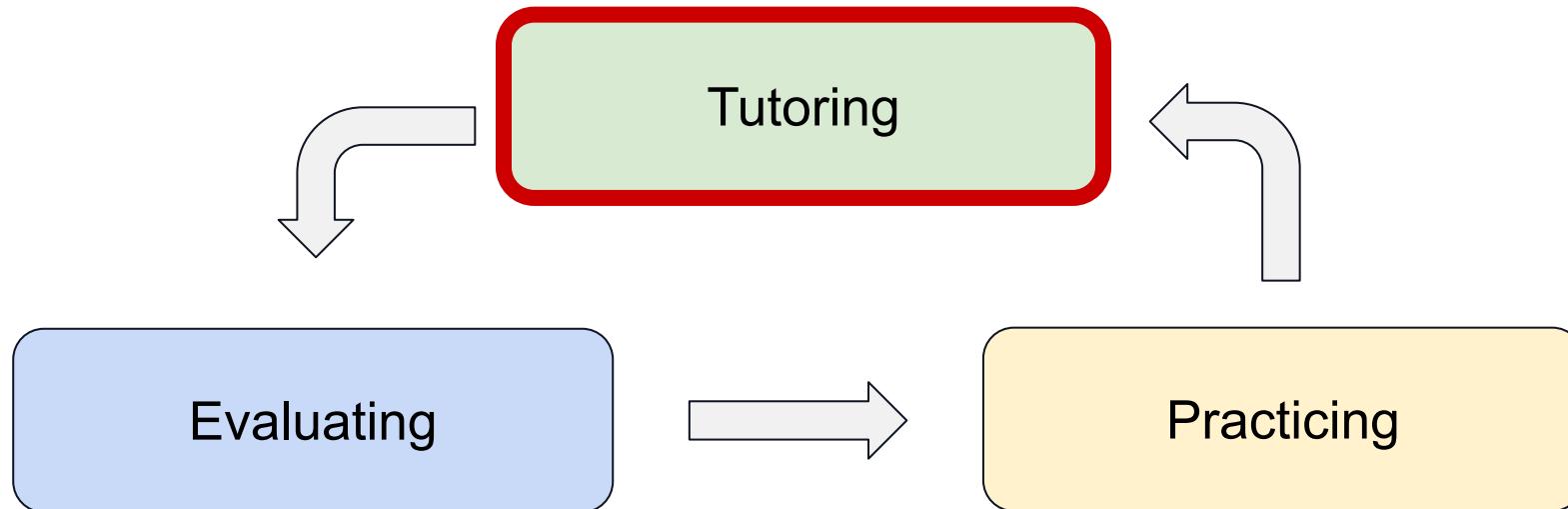


- Evaluating student learning process

- Simulating real-world environment

Generative AI's opportunities for Personalization

- Authoring personalized learning materials



- Evaluating student learning process

- Simulating real-world environment

Student Chat:

a Organelles in Eukaryotic Cells **b**

Nice to meet you, Teacher! I am Ruffle.
Thank you so much for helping me study biology. I love to learn!

Hello! I'm eager to learn about cell biology. Could you please explain what the phrase "form follows function" means in this context?

The structure of cell components and organelles evolved to support their specialized functions.

Thank you for your explanation! So, "form follows function" in cell biology means the structure of cell components and organelles supports their specialized functions.

Could you provide an example to illustrate this concept?

type here **Send**

Professor: **Request Help**

Please help the student learn the material.

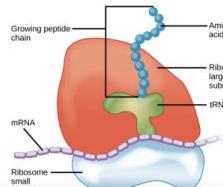
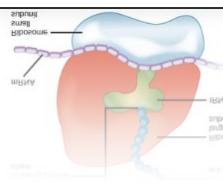
b

"Form follows function" is a philosophy that many industries follow. In architecture, this means that buildings should be constructed to support the activities housed within them. For example, a skyscraper should include several elevator banks. A hospital should have an easily accessible emergency room.

Our natural world also utilizes the principle of form following function, especially in cell biology. The structure of cell components and organelles evolved to support their specialized functions. For example, in the pancreas there are cells that are responsible for producing digestive enzymes, which are specific types of proteins that help with food digestion. In these cells, ribosomes, the organelle responsible for protein synthesis, are found in high numbers. Here the form (high number of ribosomes) follows the function (protein production). Apart from ribosomes, cells have numerous other organelles. These organelles are specialized compartments inside the cells, and similar to the organs in your body, each organelle has a unique role. In this lesson, we will dive into several examples of organelles and discuss their specific functions.

Ribosomes

Ribosomes are the cellular structures responsible for protein synthesis. They may group together into clusters (polyribosomes) or individual ribosomes may float freely in the cytoplasm. They may be attached to the plasma membrane's cytoplasmic side or the endoplasmic reticulum's cytoplasmic side and the nuclear envelope's outer membrane. Ribosomes are large protein and RNA complexes, each consisting of two subunits, one large and one small (Figure 1). Ribosomes receive their "orders" for protein synthesis from the nucleus where the DNA transcribes into messenger RNA (mRNA). After transcription, the mRNA exits the nucleus and travels to the ribosomes located in the cytoplasm. The ribosomes then translate the code provided by the sequence of the nitrogenous bases in the mRNA into a specific order of amino acids linked together to form proteins. Amino acids are the building blocks of proteins.

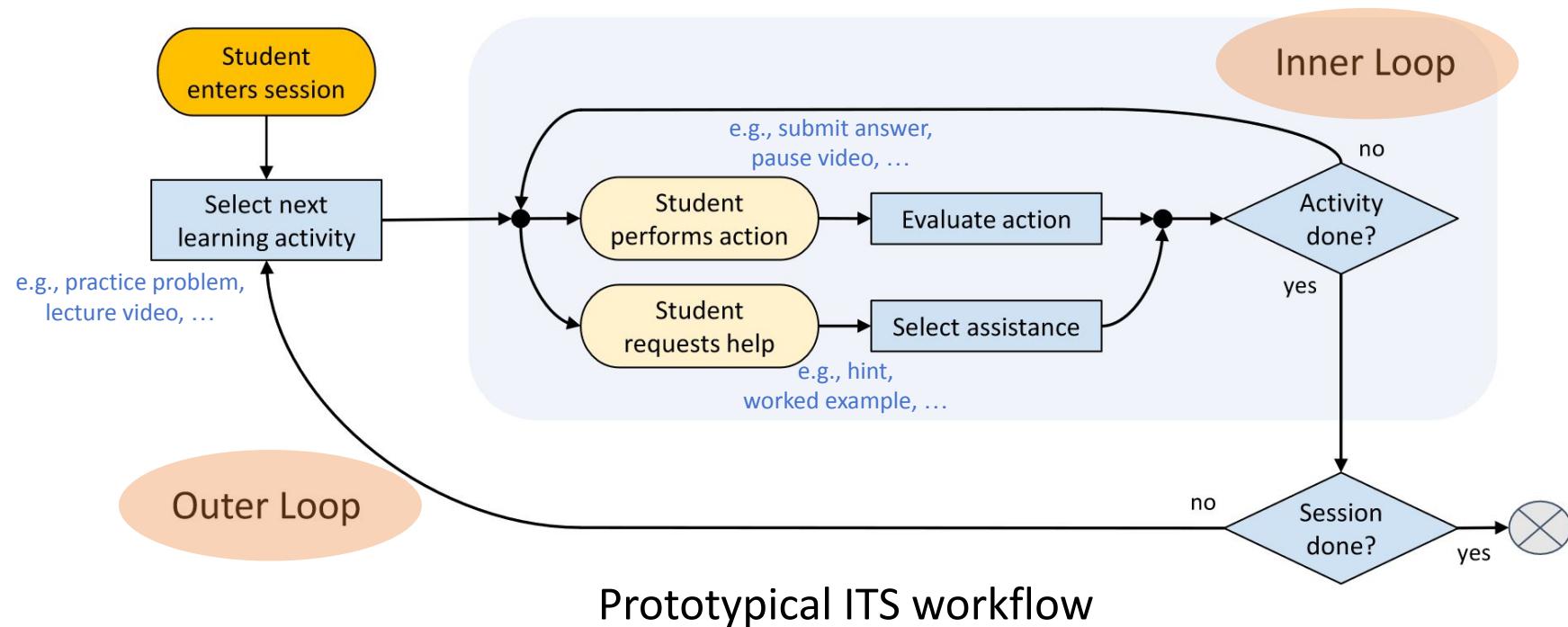



Ruffle&Riley: Insights From Designing and Evaluating a LLM-Based Conversational Tutoring System

Robin Schmucker, Meng Xia, Amos Azaria, Tom Mitchell

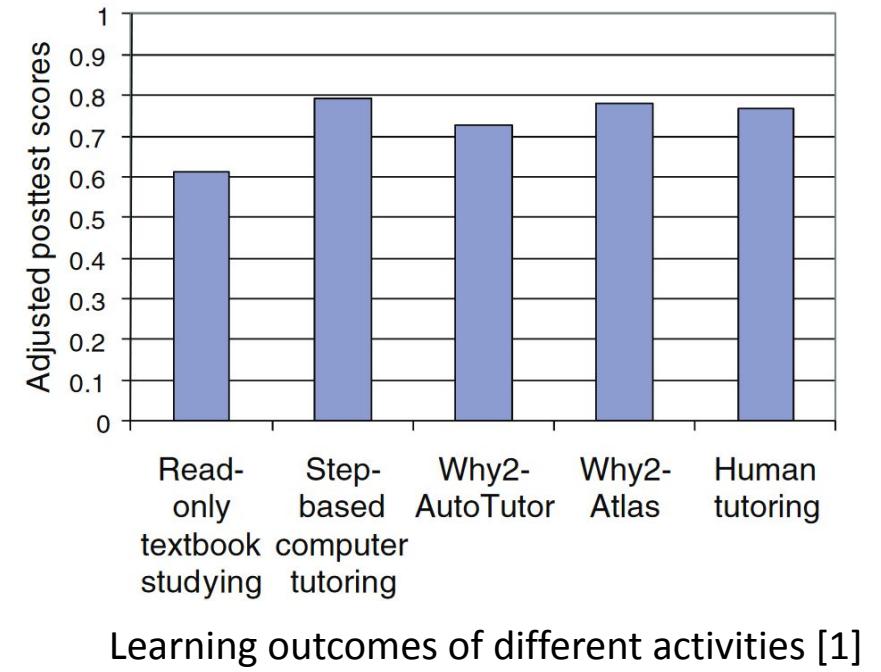
AIED 2024

Provide **personalized** and **adaptive** instruction



Benefits of ITSs:

- Can be as effective as human tutoring
- Can be scaled to millions of learners
- Provide a formal framework for thinking about tutoring processes



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

Limitations of ITSs:

- High cost of content authoring
- Limited language understanding
- Limited conversational facilities
- Limited question answering facilities

Chapter 10 AutoTutor

Arthur C. Graesser

Zhiqiang Cai

USA

USA

USA

LLMs help us address
these challenges

...y, and other
AutoTutor's
dialogues are organized around difficult questions and problems that require reasoning and explanations
in the answers. The major components of AutoTutor include an animated conversational agent, dialogue
management, speech act classification, a curriculum script, semantic evaluation of student contribu-
tions, and electronic documents (e.g., textbook and glossary). This chapter describes the computational
components of AutoTutor, the similarity of these components to human tutors, and some challenges in
handling smooth dialogue. We describe some ways that AutoTutor has been evaluated with respect to
learning gains, conversation quality, and learner impressions. AutoTutor is sufficiently modular that
it can be used in many different domains.

AutoTutor Recap [1]

[1] Graesser et al. (2012). AutoTutor. *Applied Natural Language Processing: Identification, Investigation and Resolution*, 169-187.

How can LLMs benefit ITSs?

LLMs can provide components to ITS designers:

- By generating lesson texts
- By generating question and hints
- By adding automatic grading capabilities
- By adding question answering capabilities
- ...

What would it take to generate an **entire** ITS?

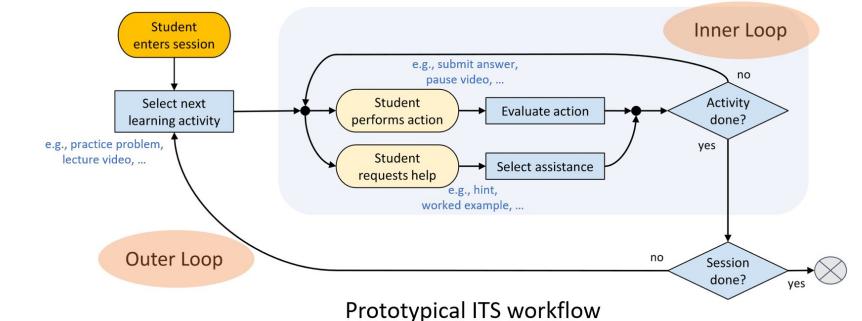
How to generate an ITS workflow?

The ITS workflow has two components:

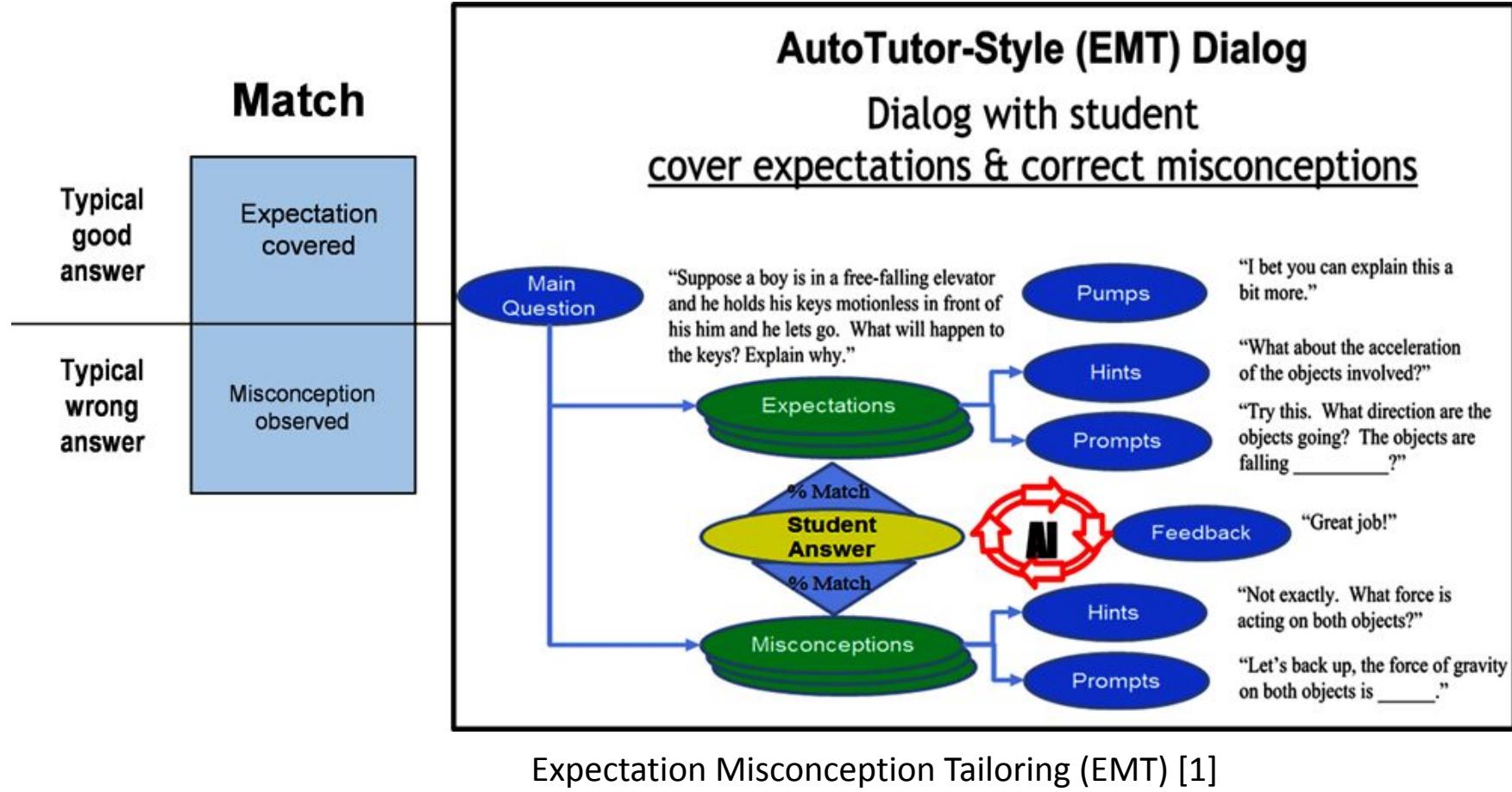
- *Outer loop*: Learning activity sequencing
- *Inner loop*: Guidance during learning activity

Playing to our strengths:

- LLMs excel at **conversational** activities

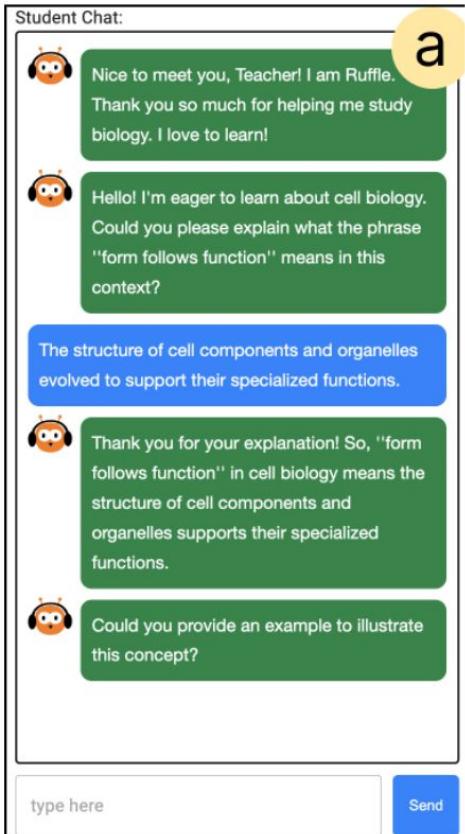


How to structure Conversational Tutoring?



Ruffle&Riley: User Interface

Free-form
dialog



a

*Pre-existing
textbook content*

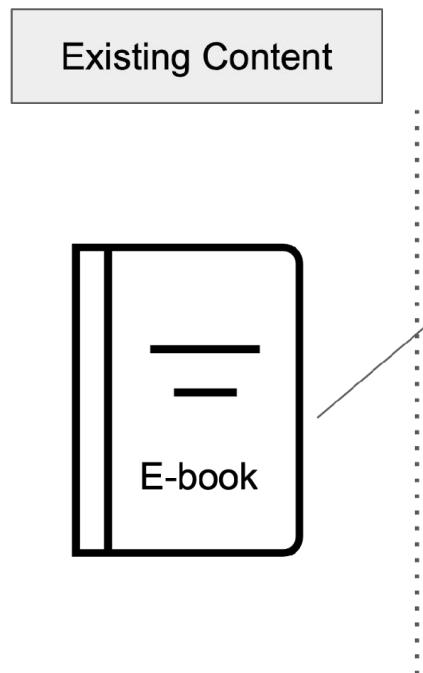
*Intelligent
Feedback*

*On demand
assistance*

*Misconcept.
Correction*

User Interface

*Facilitate tutoring **script generation** and **orchestration***



System Architecture

Enables our LLM-based agents to conduct structured workflow

Topic 1: What does the phrase "form follows function" mean in the context of cell biology? Provide an example to illustrate your answer.

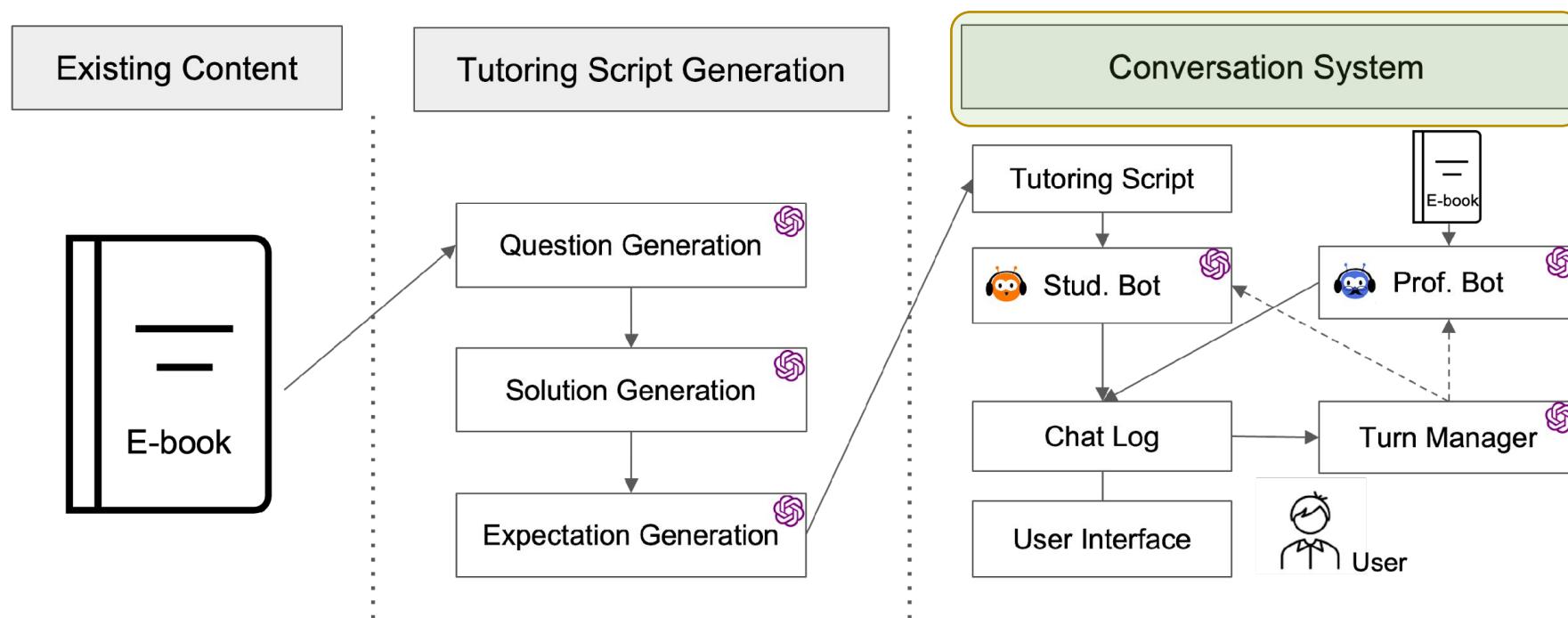
Fact 1.1: "Form follows function" in cell biology means the structure of cell components and organelles supports their specialized functions.

Fact 1.2: An example is the high number of ribosomes in pancreas cells that produce digestive enzymes, supporting their function of protein production.

Topic 2: Describe the structure and function of ribosomes. How do they contribute to protein synthesis?

...

*Facilitate tutoring **script generation** and **orchestration***



System Architecture

Conversation System

Specifies how we want to teach

Executes tutoring script as free-form conversation



Student Agent (Ruffle) :

You are an enthusiastic 18-year-old student who is trying to learn. You need the user (who is a teacher) to teach you all topics in the material. You have access to a list of topics and facts that the teacher needs to convey to you. You must learn one topic at a time. This is the list of topics you found on the internet that you need the user to slowly teach you (in order): + {TUTORING-SCRIPT}

Ask the user (who is the teacher) to teach you the material, little by little. If the teacher gives an answer, you must (a) show appreciation and summarize the answer; (b) insert [SMILE]; and then (c) ask a follow-up question that does not give the solution away if the teacher has not touched all facts about the current topic OR ask a question about the next topic. Do not move on to the next question before getting an answer for your current question. If the teacher doesn't know something, tell the teacher you will be thrilled if the teacher can check it and get back to you. When all the topics are covered, thank the teacher, say I've asked all the questions.

Ruffle&Riley: User Interface

Free-form dialog

a

Student Chat:

Nice to meet you, Teacher! I am Ruffle. Thank you so much for helping me study biology. I love to learn!

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Could you provide an example to illustrate this concept?

type here Send

Professor: Request Help

Please help the student learn the material.

Organelles in Eukaryotic Cells

Pre-existing textbook content

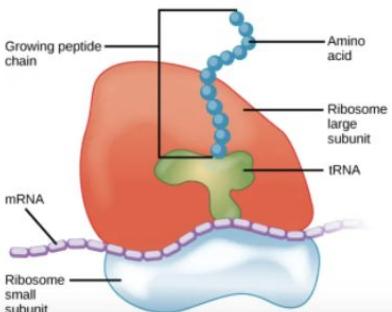
b

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User Interface

I don't know.

No worries at all! If you could request help from the professor, that would be fantastic. I'm really interested in understanding this concept better with an example.

Intelligent Feedback

On demand assistance

Professor: Request Help

Of course! You could use the example of ribosomes in the pancreas cells. These cells have a high number of ribosomes because they are responsible for producing digestive enzymes, a type of protein. Here, the form (high number of ribosomes) follows the function (protein production).

Enzymes that are produced by mitochondria

⚠ Revision required

type here

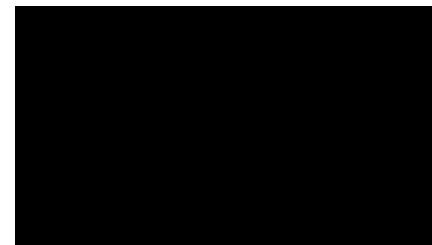
e

Misconcept. Correction

Professor: Request Help

It seems there's a small mistake in your response. Mitochondria are actually responsible for producing ATP, not enzymes. Could you please revise your response?

Ruffle&Riley: User Interface



<https://github.com/rschmucker/ruffle-and-riley>

Evaluate learning experience/test performance of 4 conditions:

1. Reading only
2. Q/A Chatbot with Human-generated questions/answers
3. Q/A Chatbot with LLM-generated questions/answers
4. Ruffle&Riley (EMT + Learning-By-Teaching)

Participants (N = 200) are free to decide how to approach learning activity

Evaluation Results

Findings of user study

Learning Experience Survey

Conditions	Learning Experience (1-strongly disagree, 7-strongly agree)						
	Engagement	Understanding	Remembering	Interruption	Coherence	Support	Enjoyment
Reading	4.33 ± 0.52	-	-	-	-	-	-
Teacher Q/A	5.0 ± 0.53	4.43 ± 0.65 *	4.43 ± 0.65 *	2.71 ± 0.64	5.43 ± 0.53	4.57 ± 0.57 *	3.71 ± 0.52 *
LLM Q/A	4.8 ± 0.47	4.4 ± 0.4 *	4.33 ± 0.42 *	2.67 ± 0.45	4.8 ± 0.43 *	4.0 ± 0.44 *	4.0 ± 0.44 *
Ruffle & Riley	5.81 ± 0.3	5.81 ± 0.24	5.76 ± 0.22	2.19 ± 0.34	6.1 ± 0.21	5.9 ± 0.26	5.62 ± 0.31

Symbol “*” marks $p < 0.05$

Findings of user study

Post-Test Performance

Conditions	Previous Knowledge	Learning Performance	
		Post-test Scores (i.e., Multiple-Choice Questions)	
Reading	2.53 ± 0.41	5.07	± 0.33
Teacher Q/A	3.0 ± 0.58	4.14	± 0.83
LLM Q/A	2.2 ± 0.3	4.67	± 0.35
Ruffle & Riley	2.67 ± 0.43	5.19	± 0.25

Symbol “*” marks $p < 0.05$

Evaluation Results

Findings of user study

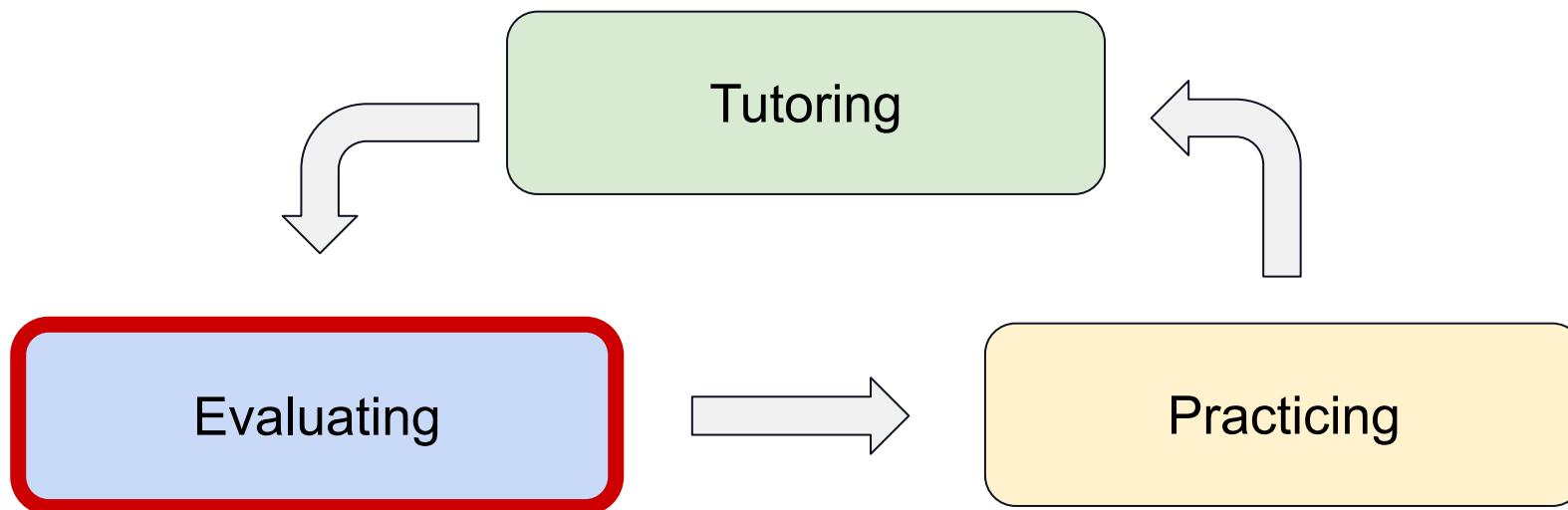
Learning Gains

Conditions	Pre-test Score	Post-test Score	Learning Gain	
			Absolute	Normalized
Reading	1.37 ± 0.17	3.53 ± 0.25	2.16 ± 0.25	0.44 ± 0.07
Ruffle&Riley	1.54 ± 0.23	3.49 ± 0.28	1.94 ± 0.26	0.47 ± 0.05

Symbol “*” marks $p < 0.05$

Generative AI's opportunities for Personalization

- Authoring personalized learning materials



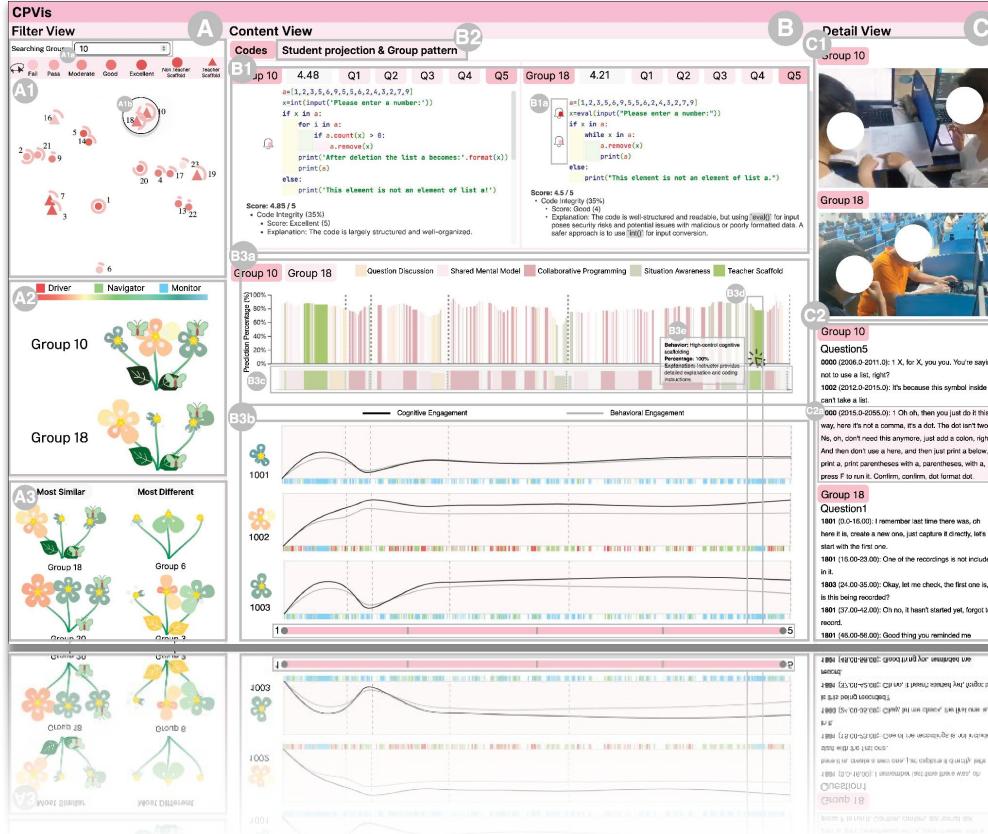
- Evaluating student learning process

- Simulating real-world environment

CPVis: Evidence-based Multimodal Learning Analytics for Evaluation in Collaborative Programming

Gefei Zhang, Shenming Ji, Yicao Li, Jingwei Tang, Jihong Ding,
Meng Xia*, Guodao Sun, Ronghua Liang

CHI 2025 (Conditionally Accepted)



Background



Challenges

- Viewing Students' Code is A Pain
- Student work is often assessed only by the final solution
- Difficulty in understanding students' engagement in problem-solving

```
a = [1, 5, 9, 10, 13]
b = [4, 6, 8, 11, 14, 15]
c = [0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
d = [1, 2, 3, 4, 5, 6, 7, 8, 9]
e = [3, 4, 5, 6, 7, 8, 9, 10]

for n in f:
    for b in e:
        for c in a:
            for d in a:
                if b ** n + c ** n + d ** n == 100 * b + 10 * c + d:
                    print(b, c, d)

for i in range(100, 1000):
    j = i // 100
    k = i // 10 % 10
    l = i % 10
    if i == j ** 3 + k ** 3 + l ** 3:
        print(i)

a = [49, 38, 65, 97, 76, 13, 27, 55, 4]
a.sort()
print(a)

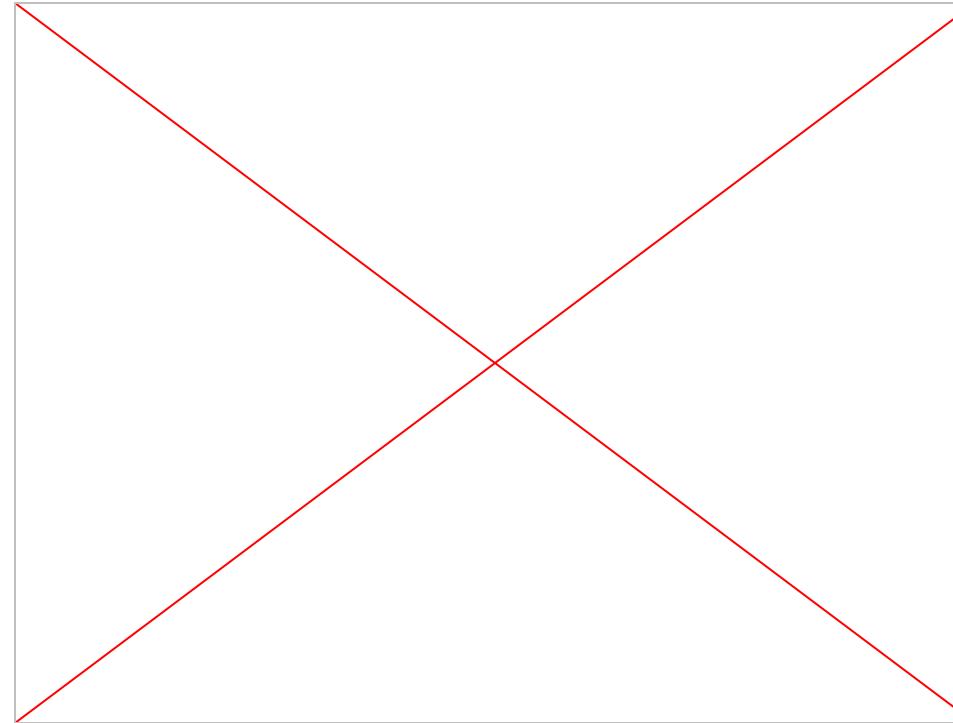
a = [1, 5, 9, 10, 13]
b = [4, 6, 8, 11, 14, 15]
c = a + b
c.sort()
```

Dataset

21 groups, 3 students per group in one class session (five coding problems)

- audio
- video
- screen sharing
- codes

System demo



Generative AI's Roles

CPVis

A Filter View

Searching Group: 10

Fail Pass Moderate Good Excellent Non Teacher Scaffold Teacher Scaffold

A1 A scatter plot showing student performance (Fail, Pass, Moderate, Good, Excellent) and scaffold usage (Non Teacher Scaffold, Teacher Scaffold) for Group 10. Students are numbered 1 through 23.

A2 A color-coded legend for Driver (red), Navigator (green), and Monitor (blue).

A3 A comparison section titled "Most Similar" and "Most Different" showing flower icons for Group 18, Group 6, Group 20, and Group 3.

B Content View

B1 Group 10 Score: 4.48

```
a=[1,2,3,5,6,9,5,5,6,2,4,3,2,7,9]
x=int(input("Please enter a number:"))
if x in a:
    for i in a:
        if a.count(x) > 0:
            a.remove(x)
    print('After deletion the list a becomes:'.format(x))
    print(a)
else:
    print('This element is not an element of list a!')
```

B2 Student projection & Group pattern

B1a Group 18 Score: 4.21

```
a=[1,2,3,5,6,9,5,5,6,2,4,3,2,7,9]
x=int(input("Please enter a number:"))
if x in a:
    while x in a:
        a.remove(x)
    print(a)
else:
    print("This element is not an element of list a.")
```

B3a Group 10 Group 18 Question Discussion Shared Mental Model Collaborative Programming Situation Awareness Teacher Scaffold

B3c Bar chart showing Prediction Percentage (%) for various engagement categories across Group 10 and Group 18.

B3d Bar chart showing Behavior: High-control cognitive scaffolding Percentage: 100% Explanation: Instructor provided detailed explanation and coding instructions.

B3e Line graph showing Cognitive Engagement and Behavioral Engagement over time for students 1001, 1002, and 1003.

C Detail View

C1 Group 10

C2 Group 18

C2a Group 10 Question5

0000 (2006.0-2011.0): 1 X, for X, you you. You're saying not to use a list, right?

1002 (2012.0-2015.0): It's because this symbol inside can't take a list.

1000 (2015.0-2055.0): 1 Oh oh, then you just do it this way, here it's not a comma, it's a dot. The dot isn't two Ns, oh, don't need this anymore, just add a colon, right? And then don't use a here, and then just print a below, print a, print parentheses with a, parentheses, with a, press F to run it. Confirm, confirm, dot format dot.

C2b Group 18 Question1

1801 (0.0-16.00): I remember last time there was, oh here it is, create a new one, just capture it directly, let's start with the first one.

1801 (16.00-23.00): One of the recordings is not included in it.

1803 (24.00-35.00): Okay, let me check, the first one is, is this being recorded?

1801 (37.00-42.00): Oh no, it hasn't started yet, forgot to record.

1801 (46.00-56.00): Good thing you reminded me

Categories	Communication behaviors	Definitions	Examples
Question Discussion	Material reading [68]	Students read the distributed material together.	"Let's go over the handout the teacher gave us."
	Question allocation [78]	Students explicitly assign a question to others or proactively self allocates a task.	"You debug the code, I'll write the test cases."
	Question planning [78]	Students list several questions remaining to be done to provoke subsequent question allocation.	"We still need to write the test cases debug the code."
	Question understanding [58]	Students explore programming with peers without providing detailed descriptions of Python coding.	"There's a problem. This one hasn't been modified."
	Information sharing [78]	Students proactively share information that no one asked.	"I found a better algorithm that improves efficiency."
Shared Mental Model	Information request [78]	Students ask someone else a question to obtain information.	"How should this function work?"
	Responding to request [78]	Students provide information in response to a asked question.	"This function takes two arguments....."
	Acknowledgement [78]	Students acknowledge receipt of information from others.	"Okay", "I agree", "Got it"
	Debugging [68]	Students are debugging the final code.	"There's a bug here, I need to double-check the values"
Collaborative Programming	Python coding [58]	Students provide detailed explanations of programming.	"You switch to the function remove"
	Print and evaluate code[58]	Students write and test code in a cyclical process, continuously writing and testing.	"Let me run the code to see the results and then tweak it."
	Escalation [78]	Students ask for assistance from the instructor either verbally.	"I think we need to ask the teacher about this."
Situation Awareness	Unrelated chat among students [58]	Students engage in unrelated conversations with peers.	"What are the other groups doing?"
	Difficult-to-reconcile conflicts [68]	Students encounter conflicts that are challenging to resolve.	"We've been debating which way to implement this"

Figure 1: Collaborative programming coding schemes, along with their definitions and examples.

Evaluation

We evaluated LLMs' performance in code quality by comparing it to human-labeled (two experienced educators, I1, and I2) results.

The results showed that I1 and I2 reached **93.43% agreement**, while ChatGPT-4o's annotations matched I1 and I2's annotations with **85.62% and 89.32%** consistency, respectively.

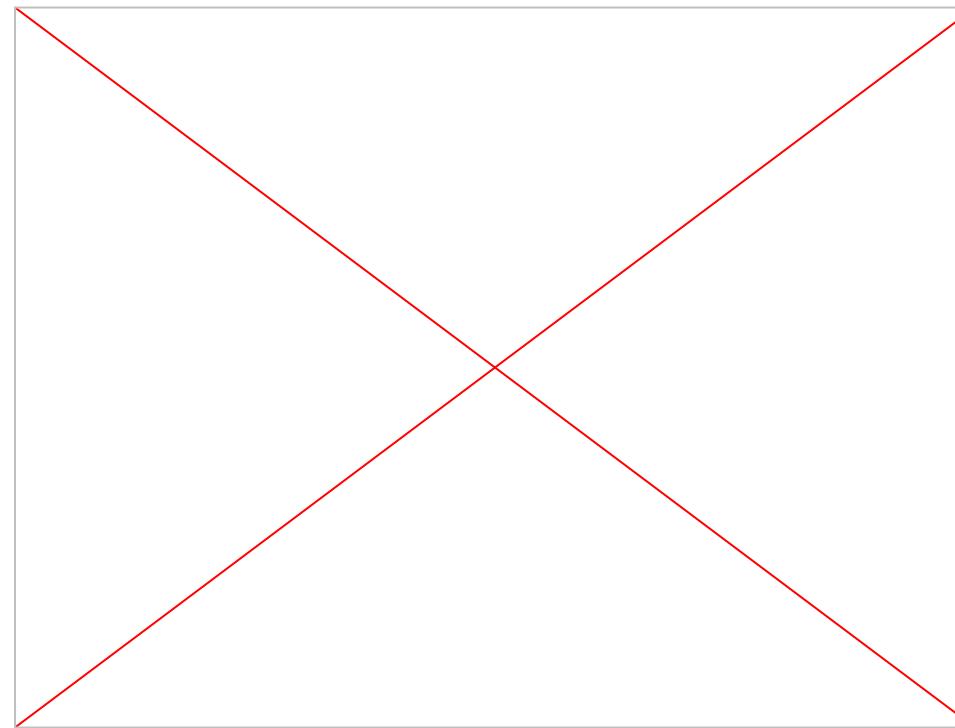
ChatGPT-4o's accuracy was relatively lower in classifying collaborative programming behaviors (90.32%) and code quality (93.43%) but higher in identifying student roles (96.54%) and teacher scaffolding (97.42%).

Mitigation

To mitigate the impact of annotation errors, we added prediction percentage and explanations to ChatGPT-4o's annotations of collaborative programming behaviors, indicating the uncertainty of classification.

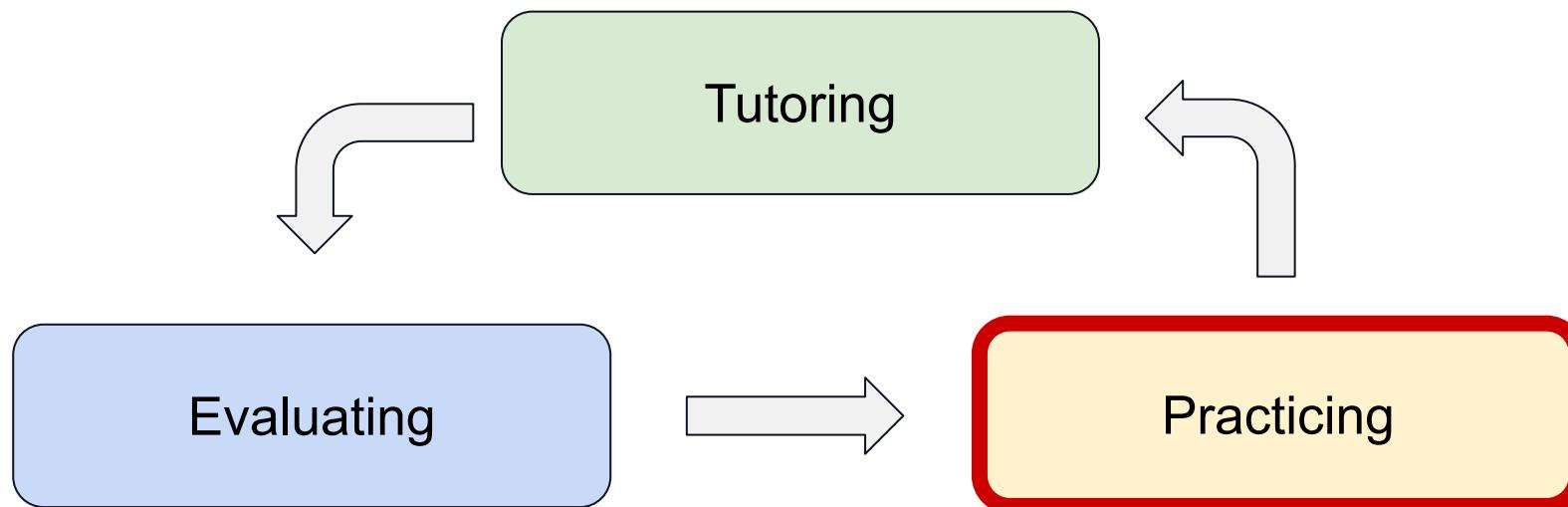
Similarly, we added explanations for code quality, providing more evidence for instructors during analysis.

Case Study and Evaluation



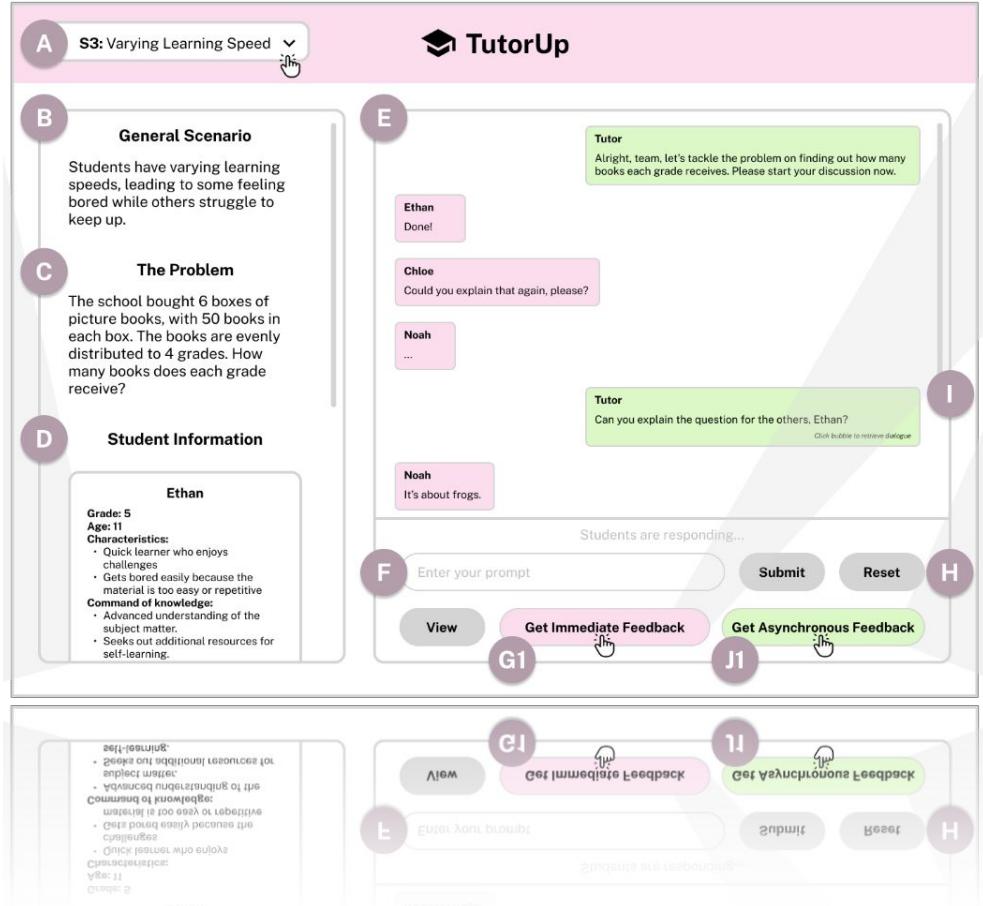
Generative AI's opportunities for Personalization

- Authoring personalized learning materials



- Evaluating student learning process

- Simulating real-world environment



TutorUp: What If Your Students Were Simulated? Training Tutors to Address Engagement Challenges in Online Learning

Sitong Pan, Robin Schmucker, Bernardo Garcia Bulle Bueno, Salome Aguilar Llanes, Fernanda Albo Alarcón, Hangxiao Zhu, Adam Teo, **Meng Xia***

CHI 2025 (Conditionally Accepted)

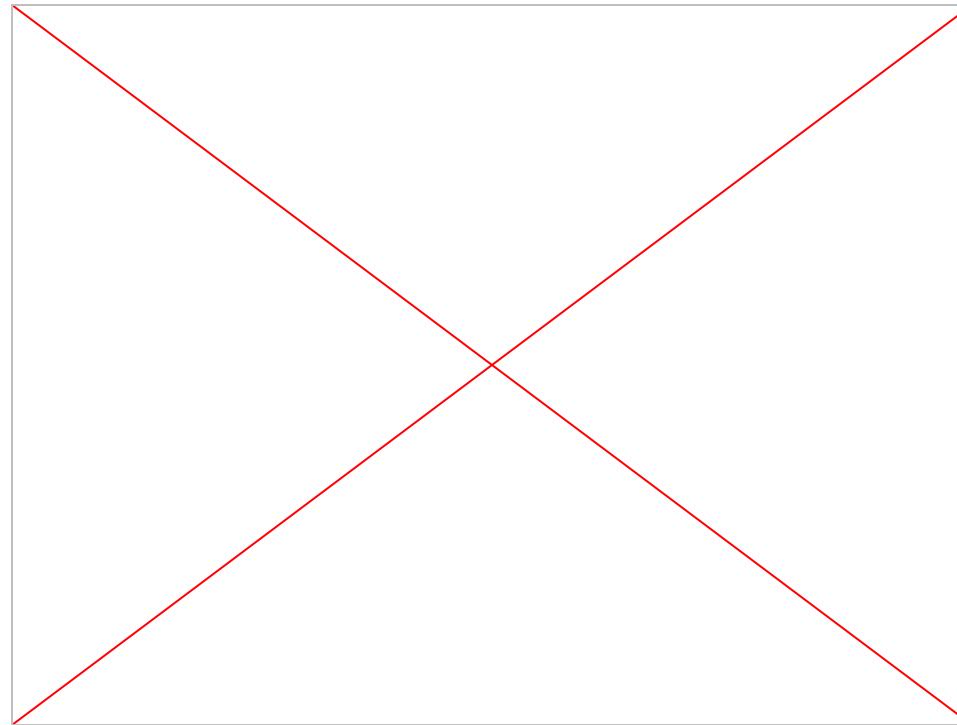
Engaging students is challenging in online learning



Identity Challenging Scenarios

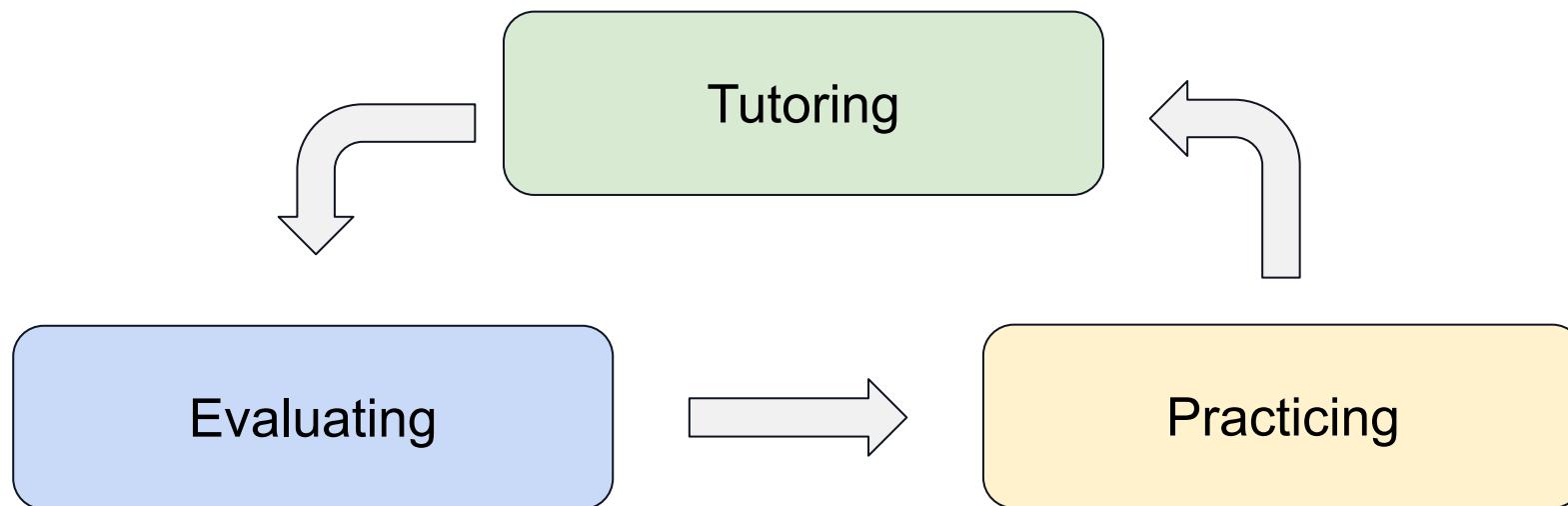
Based on a formative study involving two surveys ($N1 = 86$, $N2 = 102$) on student engagement challenges, we summarize scenarios that mimic real teaching situations:

- Lack of Interest and Engagement
- Lack of Confidence
- Varying Learning Speeds
- Fatigue and Focus Issues



Generative AI's opportunities for Personalization

- Authoring personalized learning materials



- Evaluating student learning process

- Simulating real-world environment

What are the Generative AI's challenges?

- Improper use of AI (e.g., overreliance)
- Hallucination, content inaccuracy
- Lack of pedagogical guidance



StuGPTViz: A Visual Analytics Approach to Understand Student-ChatGPT Interactions

Zixin Chen, Jiachen Wang, **Meng Xia***, Kento Shigyo, Dingdong Liu, Rong Zhang, Huamin Qu

VIS 2024

Background: An inevitable trend in using LLMs



ChatGPT



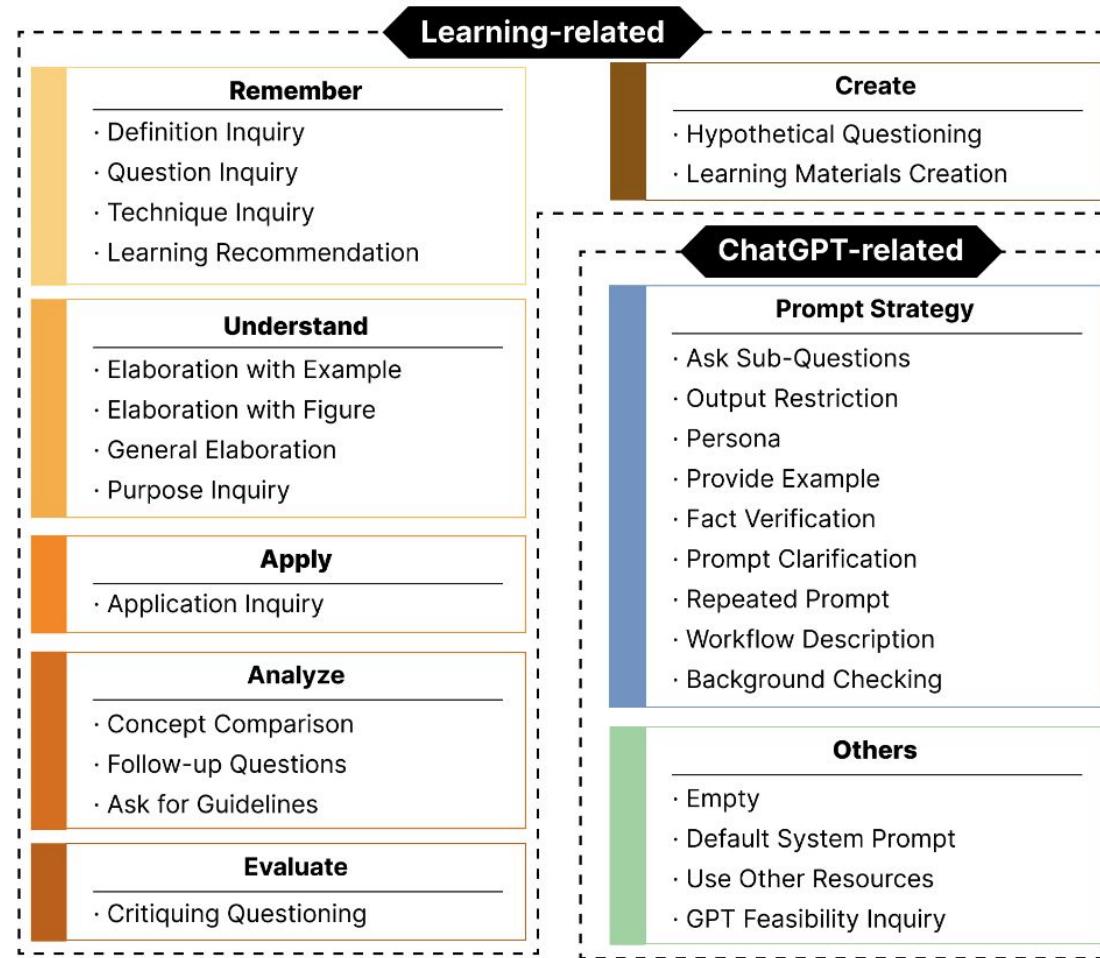
Concerns from instructors:

- How about the performance of these advanced AI tools?
- Using these advanced AI tools, can students practice higher-order thinking (e.g., independent thinking)?
- How can we better design tasks and guide students to use these advanced AI tools?

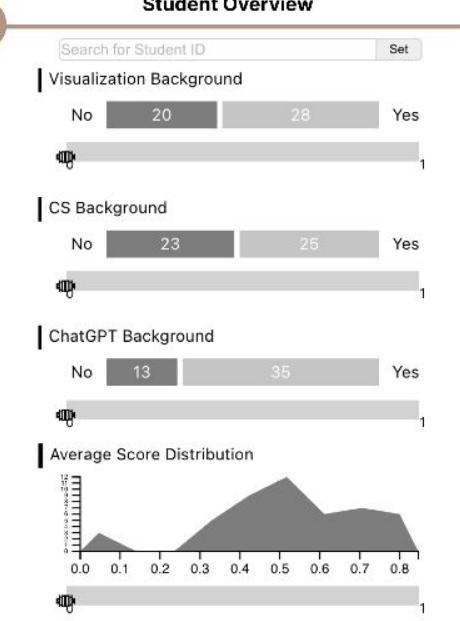
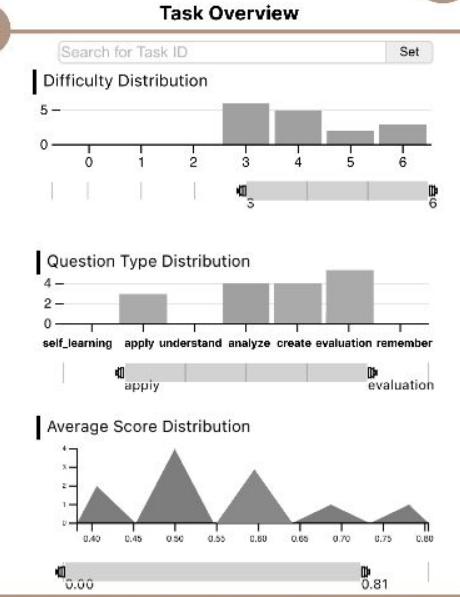
Integration of ChatGPT in Education

- We integrated ChatGPT into the curriculum of a postgraduate data visualization course for computer science majors in the first semester of 2024.
- Each in-class exercise session, we conducted the experiment during the last 40 minutes of the lecture, included a 10-minute self-learning segment with ChatGPT, a 25-minute task completion segment, and a 5-minute conversation log upload phase.
- 744 unique conversations with 2507 turns after filtering out the empty conversations and those unrelated to the learning tasks

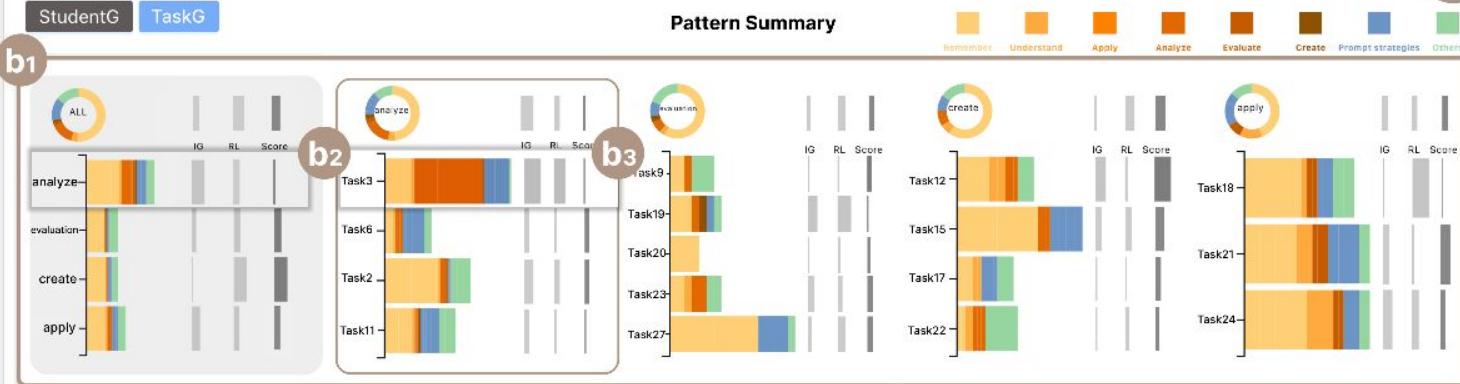
Dataset Creation with Pedagogical Insights



Filter View

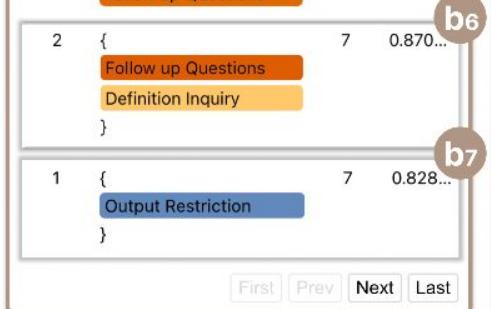
A

Pattern View

B**b4**

L...	Pattern	C...	Avg.
1	{ Follow up Questions }	17	0.806...
1	{ Question Inquiry }	16	0.5615...
1	{ Definition Inquiry }	12	0.326...
2	Follow up Questions → Follow up Questions	8	0.589...
2	{ Follow up Questions }	7	0.870...
1	{ Definition Inquiry }	7	0.828...
1	{ Output Restriction }	7	0.828...

First Prev Next Last



Detail View

C

Task Description

This diagram illustrates the updated Visual Analytics Pipeline (named the knowledge generation model), which involves a series of operations, representations, and analytical stages. Using GPT's assistance, please identify and fill in the blank nodes which associated Analytical Stages (1 to 5) in the process.

Analytical Stages

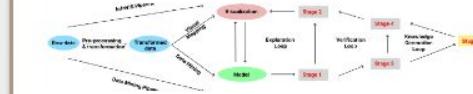
Stage 1 is [Stage_A]

Stage 2 is [Stage_B]

Stage 3 is [Stage_C]

Stage 4 is [Stage_D]

Stage 5 is [Stage_E]



Student Answer

Finding, Action, Insight, Hypothesis, Knowledge

Raw Conversation

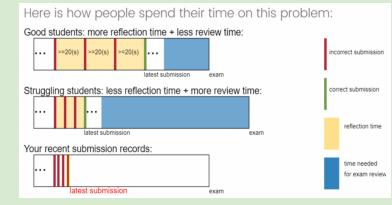
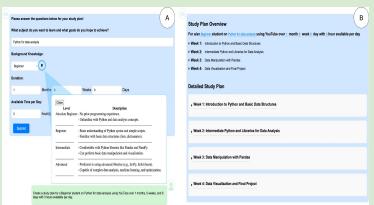
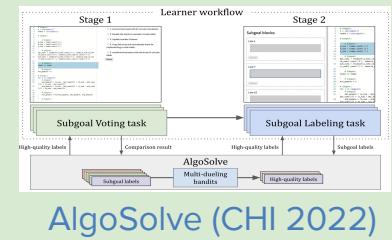
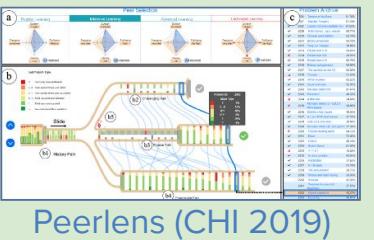
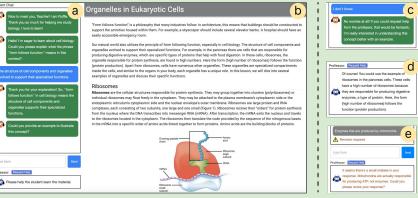
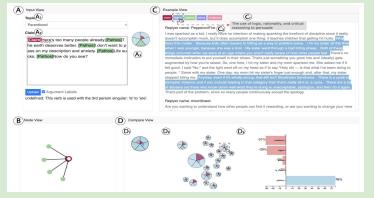
C1 Do you know the diagram of updated visual analytics pipeline

C2 Yes, the updated visual analytics pipeline typically consists of the following stages: 1. Data acquisition and integration 2. Data cleaning and preprocessing 3. Data transformation and feature extraction 4. Data mining and analysis 5. Visualization and exploration 6. Knowledge representation and reasoning 7. Decision making and action This pipeline is iterative and interactive, allowing analysts to refine their understanding of the data and adjust their analysis and visualization approaches as needed.

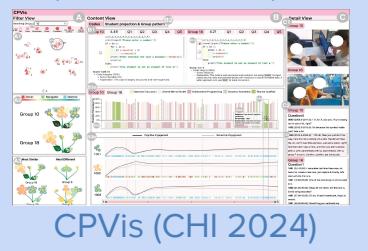
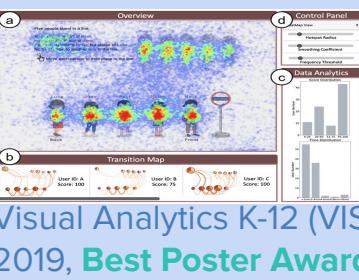
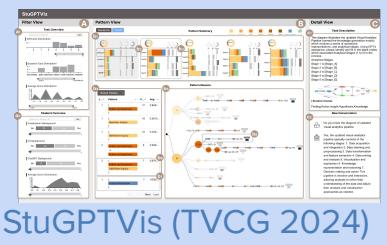
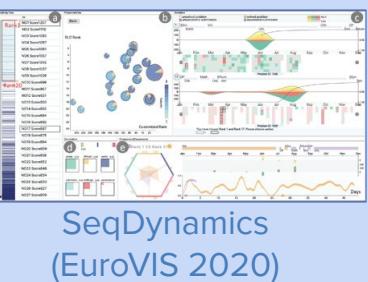
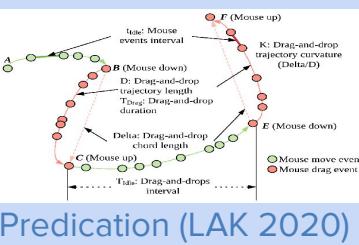
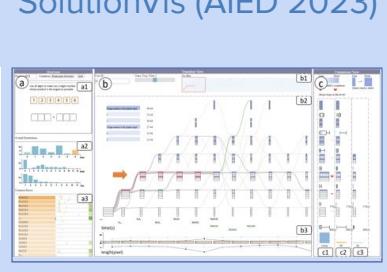
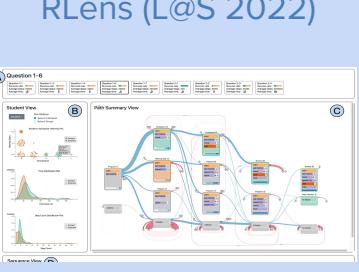
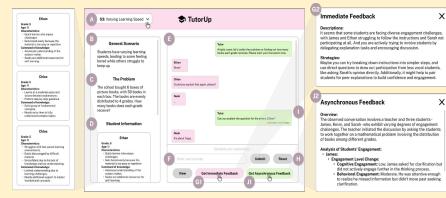
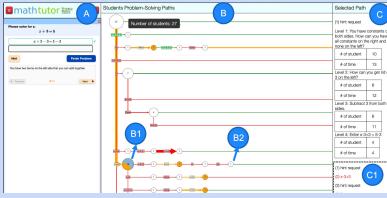
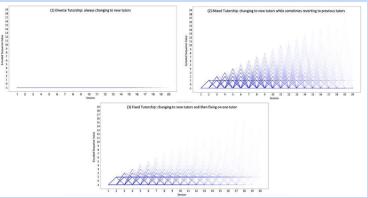
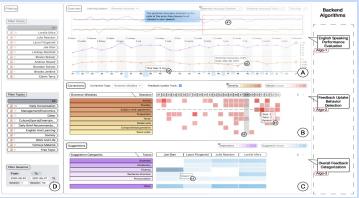
Evaluation and Result

- Students' learning perspective:
More than 90% students enjoy using ChatGPT in their learning process
- ChatGPT performance:
Strong positive correlation between the IG (information gain) metric and experts' judgment of ChatGPT's response quality
- Expert interviews:
"The ability to discern students' overall cognitive level at a glance is highly appreciated."
"The workflow's logical progression and the interconnection of each view were particularly impressive, enabling a diverse analytical focus through a unified procedure."

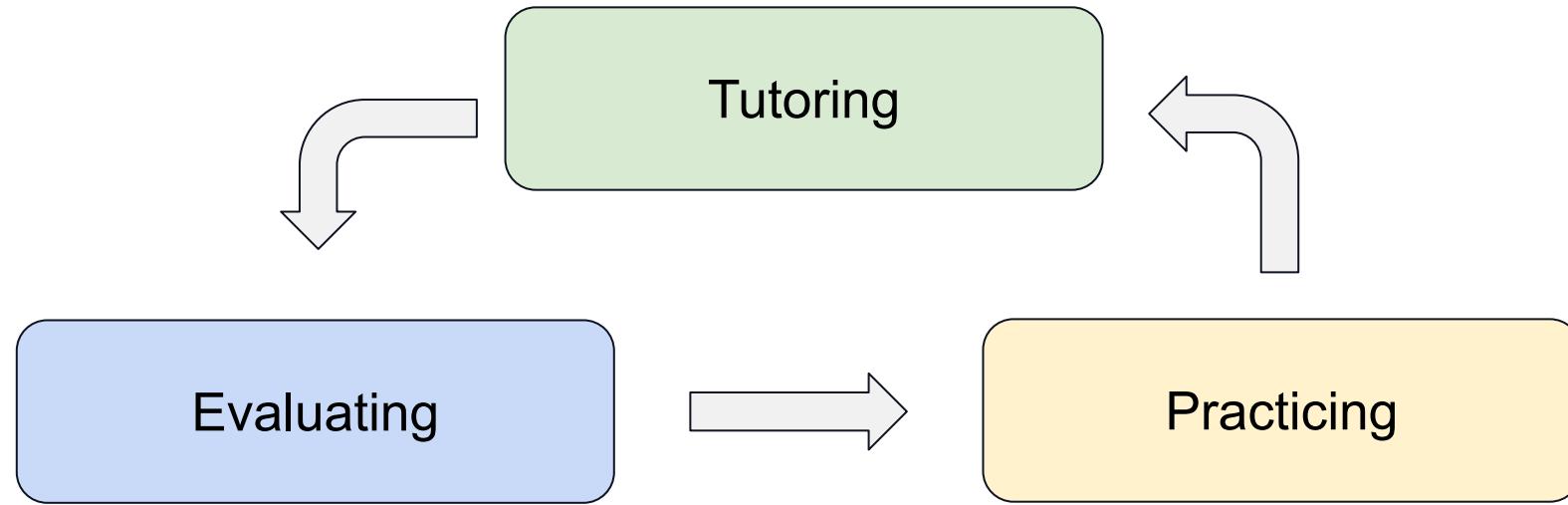
Tutoring



Evaluating



Practicing



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Graduate Students

**Jiwon Chun**

Master Student (2024 Spring)

**Gefei Zhang**

PhD Student (2024 Summer)

**Hangxiao Zhu**

PhD Student (2024 Fall)

**Yi Wen**

PhD Student (2024 Fall)

**Jing Cao**

Master Student (2024 Fall)

**Fatemeh Mirhosseini**

PhD Student (2025 Spring)

Undergrads

**Shenming Ji**Undergraduate Student (2024
Summer)**Sitong Pan**Undergraduate Student (2024
Summer)**Adam Teo**Undergraduate Student (2024
Fall)