Neurosymbolic AI for Education

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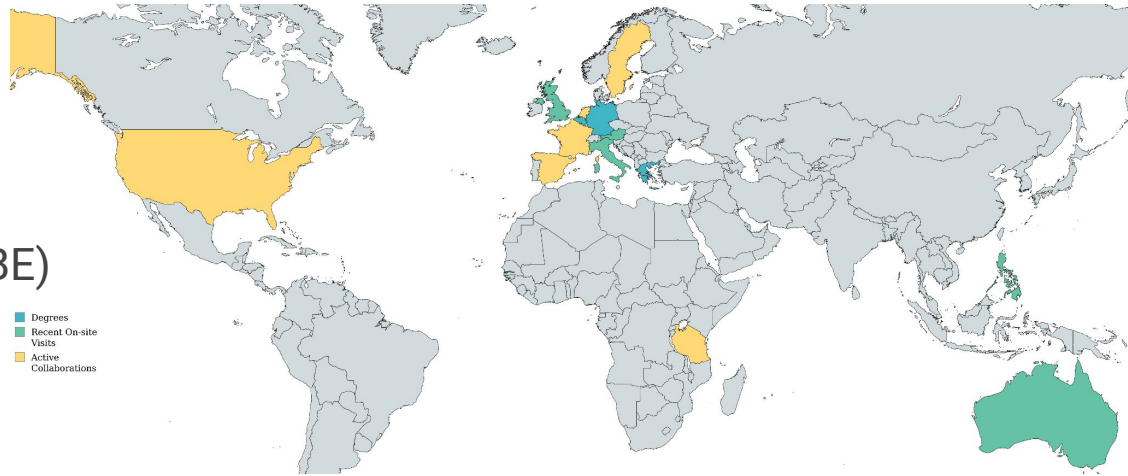
Eleni Ilkou (she/her)

Bsc Mathematics (GR)
MEng Applied Computer Science (BE)
(soon) PhD Computer Science (DE)



~10y as teacher/tutor

MCAA Alumni

Active Service in Research Community
OC: ACL'25, IJCKG'25, SEMANTiCS'26, ESWC'26
GOBLIN: Global Network on Large-Scale, Cross-domain and Multilingual Open Knowledge Graphs - Task 1.3 Leader

Currently Researcher @TIB, Germany

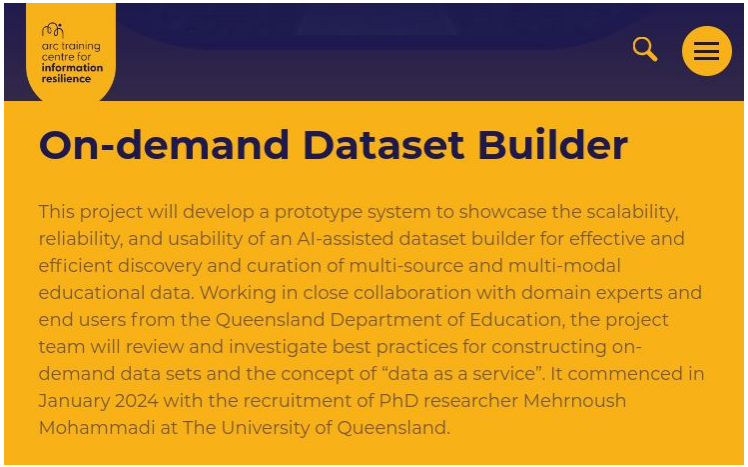
TIB LEIBNIZ INFORMATION CENTRE FOR SCIENCE AND TECHNOLOGY UNIVERSITY LIBRARY

CIRES Program

ARC Training Centre for Information Resilience (CIRES) @University of Queensland

Working with Prof. Gianluca Demartini

September - October 2025



Project Proposal:
"Benchmarking AI-Tutoring Systems"
collaboration with Assoc. Prof. Hassan Khosravi

Neurosymbolic AI for Education - Contents

Part I

- Symbolic
- Neuro

Part II

- Neuro + symbolic
- Evaluation of such systems
- Future

Symbolic

Symbolic Methods

Good Old Fashioned Artificial Intelligence (GOFAI), **explain** and **reason**

- Formal methods and programming languages,
- First-order logic rules
- Ontologies

and Knowledge Graphs

Modeling Domain (Educational KG) & Learner Model (Personal KG)

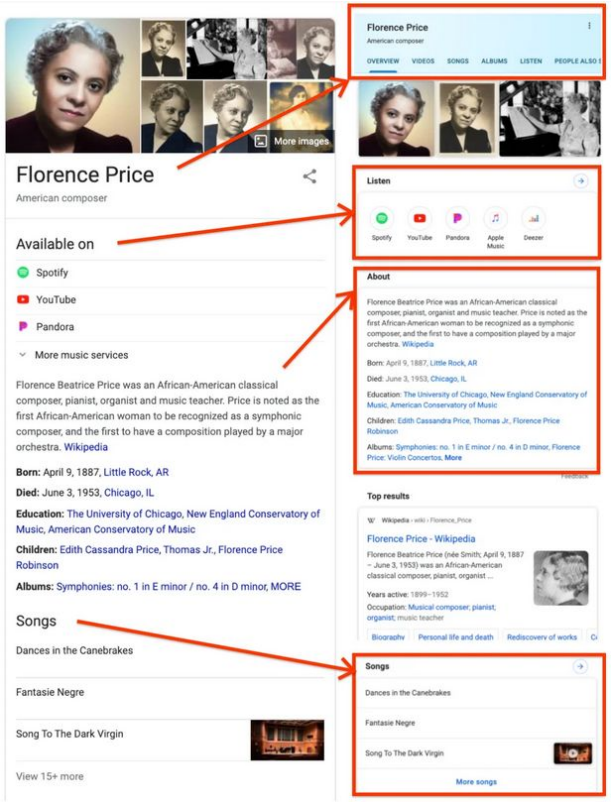
Ilkou, Eleni, and Maria Koutraki. "Symbolic vs sub-symbolic ai methods: Friends or enemies?." *CIKM (Workshops)*. Vol. 2699. 2020.

Semantics

Goal:
- Understand, interpret, and process the meaning of web data
- Smart data interoperability, integration, and automation

How:
- Metadata
- Standards for data representation, querying, reasoning
  RDF, OWL, SPARQL, FAIR data principles

Educational benefits:
- Personalized learning, resource discovery, enhanced tutoring
- Quality, credibility, explainability

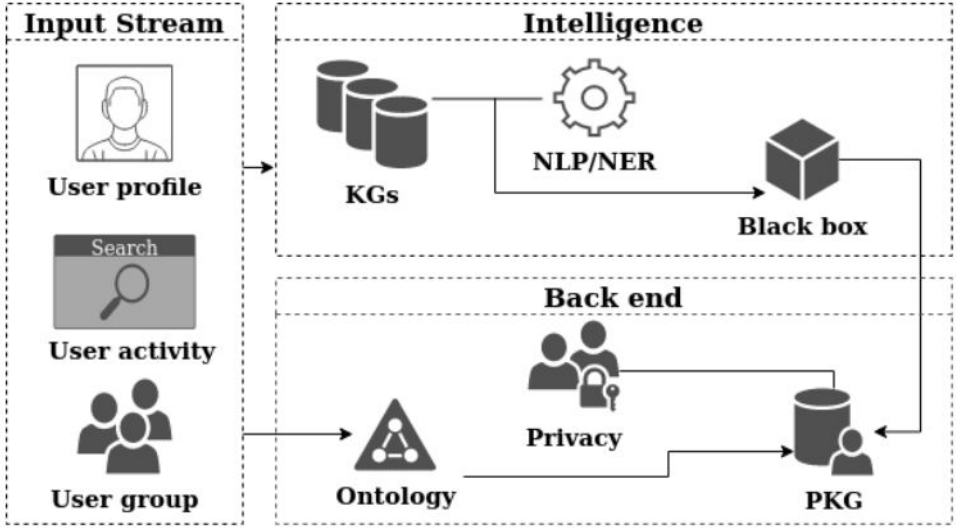


Personal Knowledge Graphs

Semantically enhanced user profiles and activity

How?
PKG (personal knowledge graph)

Understanding user knowledge state based on explicit and implicit feedback



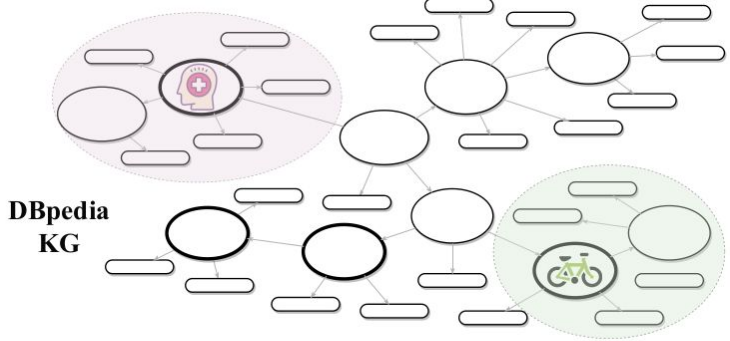
Ilkou, Eleni. "Personal knowledge graphs: Use cases in e-learning platforms." *Companion Proceedings of the Web Conference 2022*. 2022.

Collaborative Visualisations

Goal:
Summarize the important elements of each group member's contribution to the group project

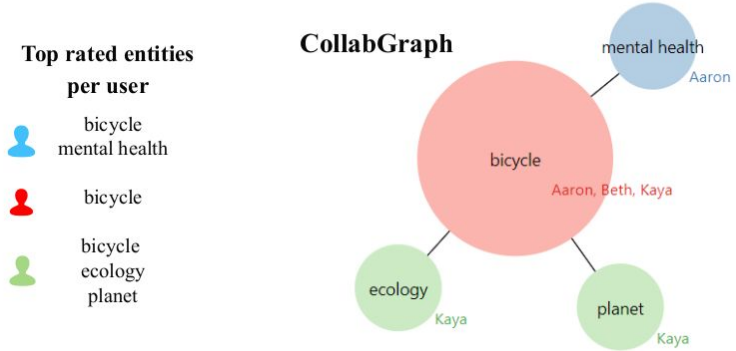
How:
Leveraging knowledge from a bigger encyclopedic Knowledge Graph (KG), ie DBpedia

We can understand what the users interests



The PKGs link to DBpedia KG and contain parts of it in their graphs

The top rated entities per user are extracted and the CollabGraph is created



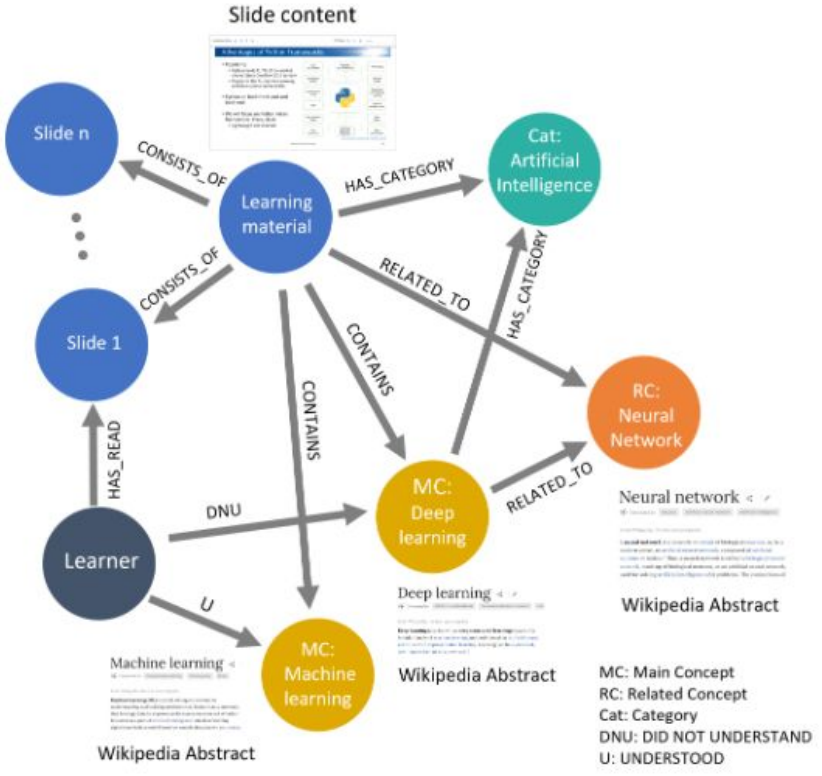
Ilkou, Eleni, et al. "CollabGraph: A Graph-Based Collaborative Search Summary Visualization." *IEEE Transactions on Learning Technologies* 16.3 (2023): 382-398.

PKGs applications (2)

Recommendations

Learning Resources based on elements the learners marked as they ‘did not understand (DNU)’

Benefits in perceived accuracy, novelty, diversity, usefulness, user satisfaction, and use intentions.



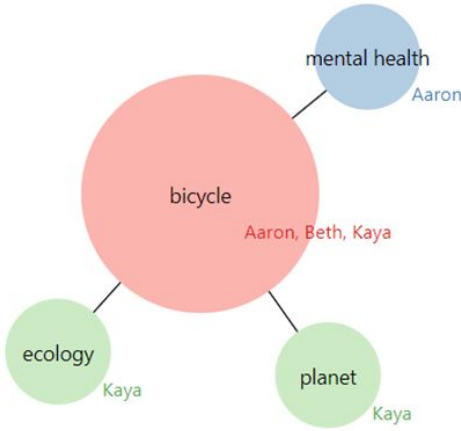
Ain, Qurat Ul, et al. "Learner Modeling and Recommendation of Learning Resources using Personal Knowledge Graphs." *Proceedings of the 14th Learning Analytics and Knowledge Conference*. 2024.

CollabGraph

The collaborative graph summary:

- is highly preferable, but cannot replace the classic search history list view
- more useful in big groups, high search activity (many search logs), and closed-end learning scenarios

The users preferred the combination of the collaborative graph summary and the list

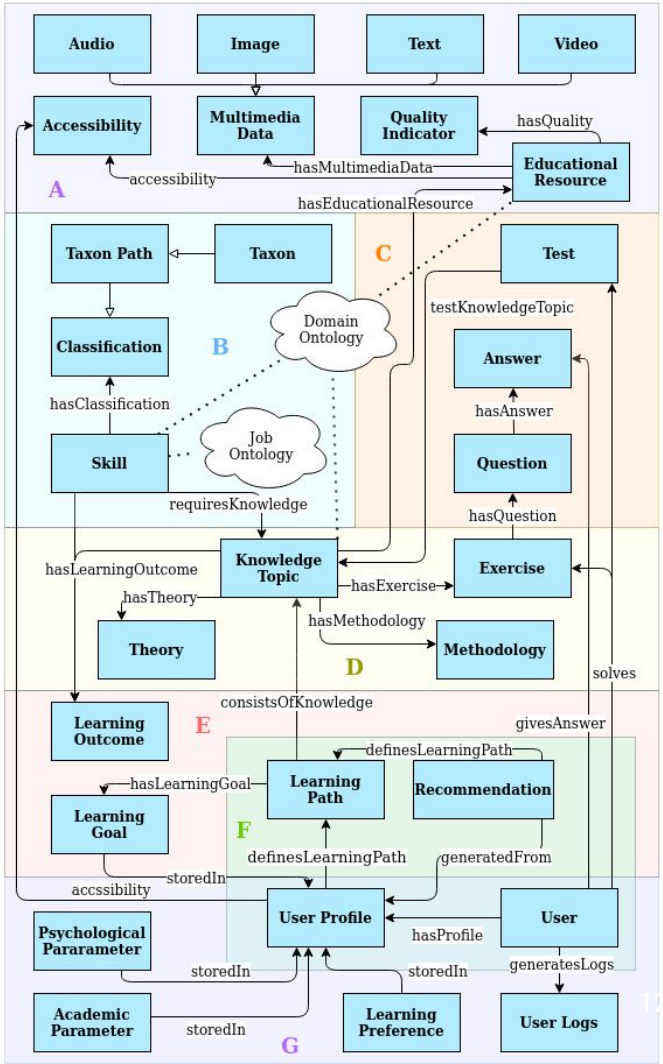


Ilkou, Eleni, et al. "CollabGraph: A Graph-Based Collaborative Search Summary Visualization." *IEEE Transactions on Learning Technologies* 16.3 (2023): 382-398.

Connecting Educational Resources

EduCOR ontology:
- high level structure for organising and connecting resources with rich metadata
- fit in different educational domains
- modularised and compatible with educational repositories

Cannot do:
Automatic alignment and mapping
Need expert intervention for populating it with specific domain data



Ilkou, Eleni, et al. "EduCOR: An educational and career-oriented recommendation ontology." *International Semantic Web Conference*. Cham: Springer International Publishing, 2021.

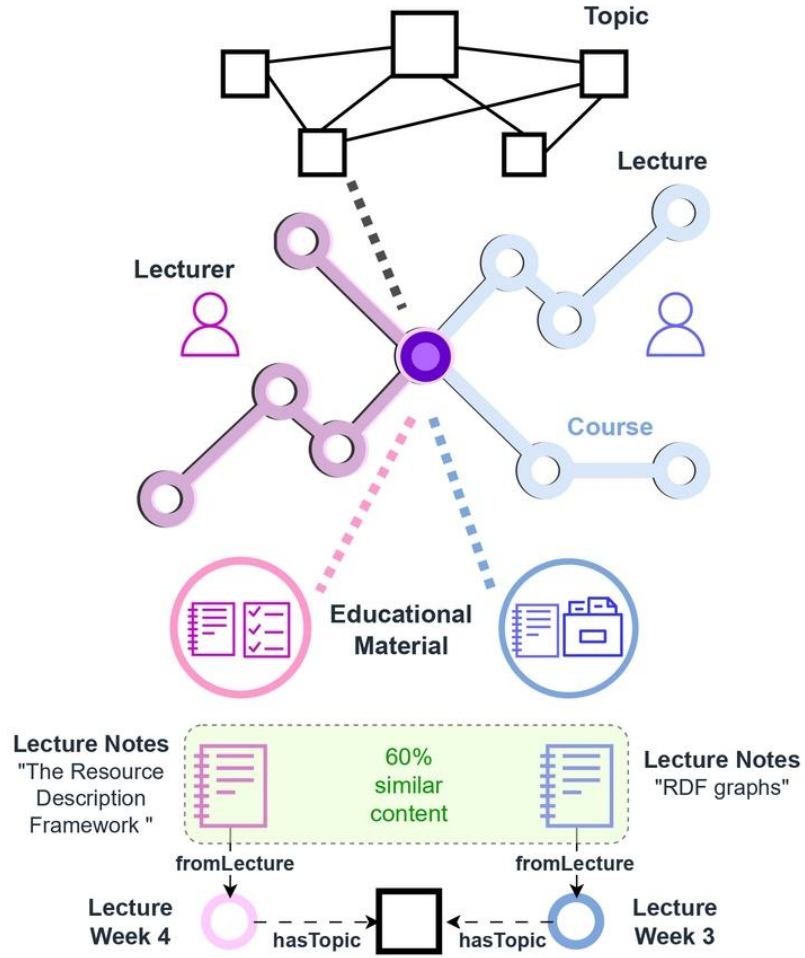
Teaching Knowledge Graph

Gathered educational resources (courses, topics, extras) from experts in Knowledge Graph courses

Goal:
– Align the resources into one structure
– Allow easy access to content
– Connect educators

Applications:
Recommend similar content, “ie Lecture X is 60% similar to yours”

Ilkou, Eleni, and Jiménez-Ruiz, Ernesto. "Towards a Knowledge Graph for Teaching Knowledge Graphs" *International Semantic Web Conference*. 2024. Honorable Mention



Neuro

Neuro Methods

Sub-symbolic, statistical learning methods, emphasis on **flexibility**

- Neural Networks
- Bayesian and deep learning

and Language Models & Generative AI models

Benefits: fitting on data, and learning from data

Issues: Lack of interpretability, restricted on critical applications, and hallucinations

Ilkou, Eleni, and Maria Koutraki. "Symbolic vs sub-symbolic ai methods: Friends or enemies?." *CIKM (Workshops)*. Vol. 2699. 2020.

LLMs for content generation & classification

Automatic Questions Generation

LLMs are capable of generating assessment questions (up to 71% correct), also Qs aligned with pedagogical frameworks ie Bloom Taxonomy
(ie up to 89.5% in agreement with experts)

Bloom's level	Description
Remember	Retrieve relevant knowledge from long-term memory.
Understand	Construct meaning from instructional messages, including oral, written, and graphic communication.
Apply	Carry out or use a procedure in a given situation.
Analyze	Break material into foundational parts and determine how parts relate to one another and the overall structure or purpose
Evaluate	Make judgments based on criteria and standards.
Create	Put elements together to form a coherent whole; reorganize into a new pattern or structure.

Content Classification

LLMs are doing better classifying their own generated educational data (ie questions with up to 86% in F1 score), rather than data found in the wild (ie topics in youtube videos with ~30% F1 score)

Scaria, Nicy, Suma Dharani Chenna, and Deepak Subramani. "Automated Educational Question Generation at Different Bloom's Skill Levels Using Large Language Models: Strategies and Evaluation." *International Conference on Artificial Intelligence in Education*. Cham: Springer Nature Switzerland, 2024.
Moein, Mohammad, et al. "Beyond Search Engines: Can Large Language Models Improve Curriculum Development?." *European Conference on Technology Enhanced Learning*. Cham: Springer Nature Switzerland, 2024.
Al Faraby, Said, and Ade Romadhony. "Analysis of llms for educational question classification and generation." *Computers and Education: Artificial Intelligence* 7 (2024): 100298.

LLMs for learning analytics

Unstructured Data Analysis

Multimodal Illustration

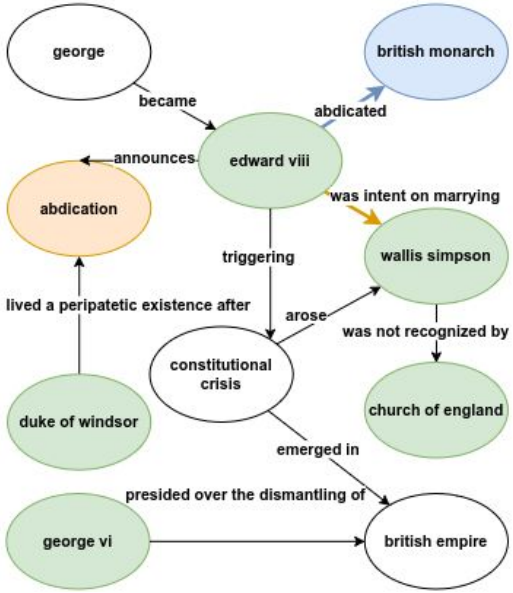
Explanatory Analytics

Interactive Analytics

For personalisation, intervention, and accessibility

Automatic Concept Maps

Generation from multiple documents



Yan, Lixiang, Roberto Martinez-Maldonado, and Dragan Gasevic. "Generative artificial intelligence in learning analytics: Contextualising opportunities and challenges through the learning analytics cycle." *Proceedings of the 14th learning analytics and knowledge conference*. 2024.

Galletti, Martina, Inès Blin, and Eleni Ilkou. "Automated Concept Map Extraction from Text." *5th Conference on Language, Data and Knowledge, 9-11 September, Naples, 2025*. 2025.

LLMs in solving math

Over GSM8K dataset, linguistically diverse grade school math word problems with problems that take between 2 and 8 steps to solve

- fine-tuning alone LLMs achieve performance lower than 60% (test score)
- 5-shot Chain of Thought achieves up to 92%
- Chain of Thought + Program-Aided Language Models 96.8%

⟹ LLMs + quality reference data = better performance

Sundaram, Sowmya S., et al. "Does a language model “understand” high school math? A survey of deep learning based word problem solvers." *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery* (2024): e1534
Cobbe, Karl, et al. "Training verifiers to solve math word problems." *arXiv preprint arXiv:2110.14168* (2021).

Neuro + Symbolic

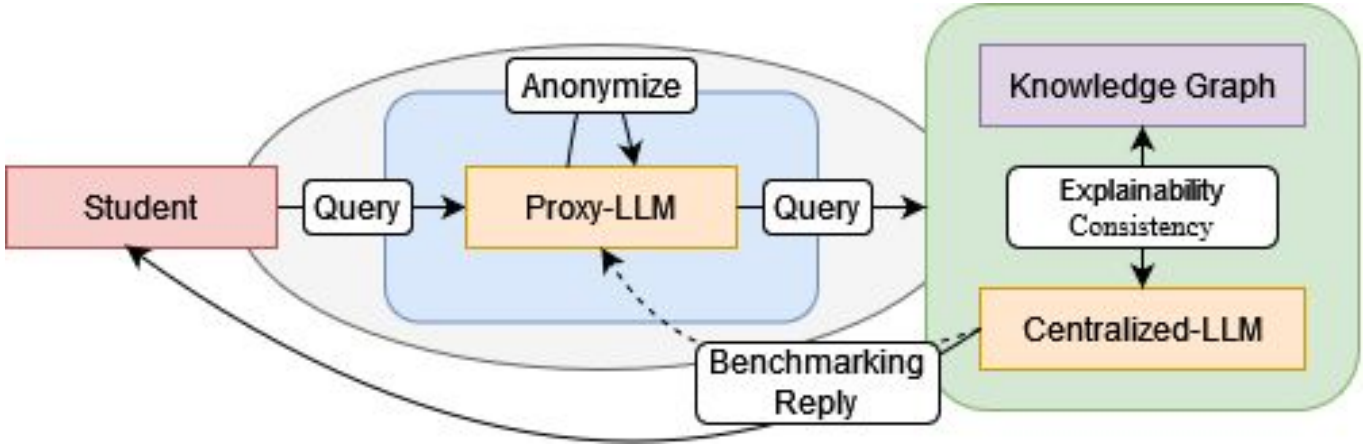
Neurosymbolic = RAG

Retrieval-Augmented Generation (RAG) is a popular example of neurosymbolic architectures:

- Neural part: A (large) Language Model that generates output and communicates with users
- Symbolic part: The structured knowledge system (database, textbook, Knowledge Graph) that provides the facts (knowledge)

RAG: Socratic Tutor

LLMs with Knowledge Engineering and Hybrid Human AI components



Ilkou, Eleni, Stephan Linzbach, and Jonas Wallat. "Hybrid Evaluation of Socratic Questioning for Teaching." *ISWC Special Session*. 2024

Solving Math with Socratic Subquestions

A carnival snack booth made $50 selling popcorn each day. It made three times as much selling cotton candy. For a 5-day activity, the booth has to pay $30 rent and $75 for the cost of the ingredients. How much did the booth earn for 5 days after paying the rent and the cost of ingredients?

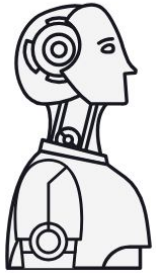
How much did the booth make selling cotton candy each day?
** The booth made $50 x 3 = $<<50*3=150>>150 selling cotton candy each day.

How much did the booth make in a day?
** In a day, the booth made a total of $150 + $50 = $<<150+50=200>>200.

How much did the booth make in 5 days?
** In 5 days, they made a total of $200 x 5 = $<<200*5=1000>>1000.

How much did the booth have to pay?
** The booth has to pay a total of $30 + $75 = $<<30+75=105>>105.

How much did the booth earn after paying the rent and the cost of ingredients?
** Thus, the booth earned $1000 - $105 = $<<1000-105=895>>895.



How much did the booth make selling cotton candy each day?

How much did the booth make in a day?

Cobbe, Karl, et al. "Training verifiers to solve math word problems." *arXiv preprint arXiv:2110.14168* (2021). [Open AI 2.5k citations]

Adaptation in Socratic Tutoring Systems

(a) Difficulty adaptation (b) Cultural adaptation (c) Emotional adaptation

Ilkou, Eleni, Stephan Linzbach, and Jonas Wallat. "Hybrid Evaluation of Socratic Questioning for Teaching." *ISWC Special Session*. 2024

Evaluation

Evaluation of Socratic RAG systems

Technical competence	Dependencies		
	GenAI	KE	HHAI
Single component responsibility			
Learning path and goal detection [5]		X	
Quality-guaranteed educational resources		X	
Modular knowledge units		X	
Alternative examples retrieval		X	
Memory of previous interactions	X		
Reliable explanations on replies	X		
Medium of communication and presentation of replies			X
Multi component responsibility			
Privacy and disclosure of personal information	X		X
Generation of different types of Socratic questions [6]	X	X	
Contextual awareness and understanding of universal definitions [7]	X	X	
Prior knowledge and prerequisites detection		X	X
Adaptive difficulty adjustment [8]	X	X	
Learner current and prior knowledge state detection	X	X	X
Tutor interpretability	X	X	
Tutor knowledge consistency	X	X	
Tutor flexibility and adaptive questioning based on responses	X	X	X
Accessibility options	X	X	X
Clear and fast communication	X		X
Emotional state and non-verbal cues detection	X		X
Empathetic and cultural sensitive communication	X	X	X

We usually face competences as single domain responsibilities

Moving forward we'll need hybrid benchmarks and metrics

Ilkou, Eleni, Stephan Linzbach, and Jonas Wallat. "Hybrid Evaluation of Socratic Questioning for Teaching." *ISWC Special Session*. 2024

Efforts towards hybrid evaluations

BEA challenge @ACL 2025 -
Logs from LLM-tutoring guidance

Evaluation metrics (binary) on:

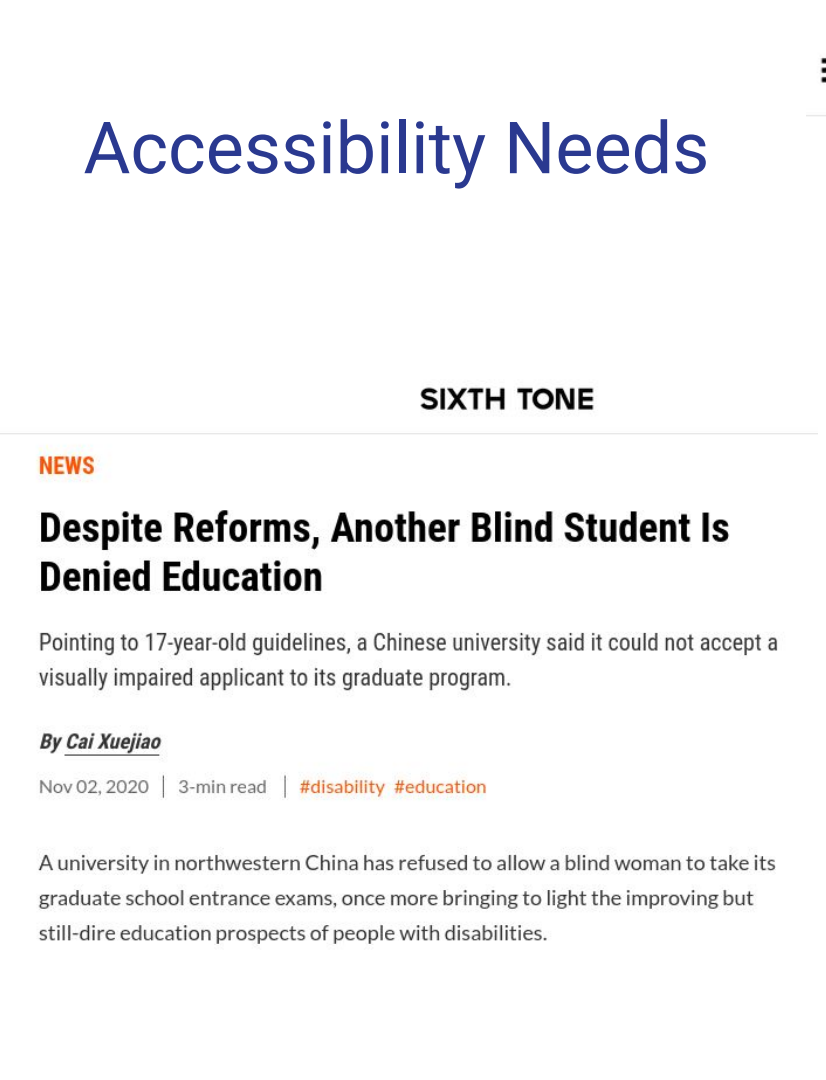
- Mistake identification
- Mistake location
- Providing guidance
- Actionability

Tutor: What is 25 minus 18?
Student: 8"

"response": "Please recheck your answer.",

"annotation": {
"Mistake_Identification": "Yes",
"Mistake_Location": "Yes",
"Providing_Guidance": "No",
"Actionability": "To some extent"
}

Accessibility Needs



SIXTH TONE

NEWS

Despite Reforms, Another Blind Student Is Denied Education

Pointing to 17-year-old guidelines, a Chinese university said it could not accept a visually impaired applicant to its graduate program.

By Cai Xuejiao

Nov 02, 2020 | 3-min read | #disability #education

A university in northwestern China has refused to allow a blind woman to take its graduate school entrance exams, once more bringing to light the improving but still-dire education prospects of people with disabilities.

BBC

Register Sign In

Blind University of Glasgow student 'faced reading list discrimination'

28 August 2019

Share Save

Jamilla Malik

BBC's Victoria Derbyshire programme

The University News

BY STUDENTS, FOR STUDENTS. SINCE 1921

Campus News

Students denied accommodations in class, call out university for accessibility failures

As students demand accessible education, they face limited resources and pushback from professors

Lauren Hutchens, Editor-in-chief • NOVEMBER 22, 2024

Effect of WWII

WWII accelerated the growth of nationalism and shook the foundations of imperialism. The economic impact of the war on West Africa was tremendous and far reaching, resulting in (1) an increased economic importance of West Africa to the world market. Europe began to depend more on tropical Africa to supply rubber, cotton, cocoa, palm produce, and groundnuts. Thus, West African colonies increased the production of these cash crops. In Nigeria for instance, value of exports rose from 10,300,00 pounds in 1931 to 24,600,00 pounds in 1946. Imports rose from 6,800,00 pounds to 19,800,00 pounds during the same period. (2) West African workers developed grievances as a result of the colonial government introducing price control, controlling marketing of export crops, introducing wage ceilings, and pressuring for more production, Moreover, African businessmen were excluded from the import and export trade which was now reserved only for European firms. (3) The rise of trade unions emerged as a result of the rise of the cost of living without corresponding rise in wages. This provided stimulus for organizational activity among the labor class. In Nigeria the number of trade unions rose from 5 to 70, and the Nigerian Trade Union Congress (1943) became central coordinating body. Trade unions cooperated closely with nationalist leaders in pressing for the end of colonialism. (4) War resulted in speedy growth of cities as result of people flocking into cities to take up new jobs. Many West African cities more than doubled their population. Lagos rose from 100,000 in 1939 to 230,00 in 1950. Accra rose from 70,000 in 1941 to 166,00 in 1948. Towns became overcrowded with discontented job-seeker and workers who witnessed whites living in comfortable, spacious European reservations with paved streets and beautiful lawns and gardens, while they were living in slums. The people therefore became receptive to nationalist appeal and would become the first willing recruits into militant nationalist movement. (5) War gave impetus to education in West Africa. Because of increased prosperity resulting from war time economic boom, more parents could afford to send children to school, literacy spread, and newspaper readership increased. Newspapers became a powerful tool in hands of nationalists to push for political, economic and social development. (6) In spite of more job opportunities, thousands of school-leavers remained unemployed. For the first time, West African cities developed a new class of unemployed people especially in cities. They became disgruntled and blamed colonial government and European firms for their plight. They were easily won over by nationalist agitators. (7) The most decisive factor that accelerated the growth of nationalism was however the return of ex-servicemen. Over 176,000 men from British West Africa served in British colonial army during war. After war, large numbers of survivors returned. About 100,000 returned to Nigeria, and 65,000 retuned to Ghana from the Middle East, East Africa, Burma and India. Ex-service men had seen life in more developed countries and enjoyed high living standards

Effect of WWII

World War II (WWII) changed many things. It made nationalism grow faster and hurt imperialism. The war had a big effect on West Africa's economy. Some of the main impacts were:

1. **Economic Importance of West Africa:**
   WWII made West Africa more important to the world economy. Europe began relying more on tropical Africa to supply products like rubber, cotton, cocoa, palm oil, and groundnuts. Because of this, West African colonies grew more of these crops. For example, in Nigeria, the value of exports rose from £10,300,000 in 1931 to £24,600,000 in 1946. Imports also grew, from £6,800,000 to £19,800,000 during the same time.

2. **Grievances of Workers:**
   West African workers had complaints about the colonial government. The government introduced price controls, took over the marketing of crops, set limits on wages, and forced more production. African businesses were also left out of the import and export trade, which was now controlled by European companies.

3. **Growth of Trade Unions:**
   The cost of living went up, but wages did not. This led to the rise of trade unions. In Nigeria, the number of trade unions increased from 5 to 70. The Nigerian Trade Union Congress was formed in 1943 to coordinate their activities. These unions worked with nationalist leaders to fight for independence.

4. **Growth of Cities:**
   Many West African cities grew quickly because people moved to cities for new jobs. Lagos, for example, grew from 100,000 people in 1939 to 230,000 in 1950. Accra grew from 70,000 in 1941 to 166,000 in 1948. However, many cities became overcrowded. Poor workers lived in slums, while Europeans lived in comfortable areas with paved streets and gardens. This made people more open to nationalist ideas and movements.

5. **Education and Literacy:**
   The war brought economic growth, and many families could now afford to send their children to school. As a result, literacy increased, and more people started reading newspapers. These newspapers became important tools for nationalists to push for political and social changes.

6. **Unemployment among School Leavers:**
   Even though there were more job opportunities, many young people who finished school could

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Original

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Dyslexia-friendly

What is Dyslexia-friendly text?

Dyslexia accessibility of text is making a text more accessible to readers with dyslexia.

Currently, it measured via **readability indexes** Ie. LIX, BLEU, BERTScore

NOT tailored to dyslexia

There are plenty of criteria for dyslexia accessibility of text, but **no gold-standard**:

- "easy-to-read" which is supported by the United Nations
- European standards for making information easy to read and understand
- W3C has a Web Accessibility Initiative (WAI)
- Dyslexia Style Guide by the British Dyslexia Association

Language Models knowledge of dyslexia accessibility criteria is limited

No prior study in literature

We find that:

1. LMs recognize less than half of the 33 dyslexia-friendly criteria for text with Gemma **wrongly** suggesting to use Italics and green/red colour

2. LMs recommendations can be problematic

	Average Score/ %	Stand. Deviation
Gemma	10.13 / 30.7%	0.63
Phi4	**13.88 / 42.1%**	0.63
GPT4-turbo	13.00 / 39.4%	0.41

Ilkou, Eleni, et al. "Dyslexia and AI: Do Language Models Align with Dyslexic Style Guide Criteria?." *International Conference on Artificial Intelligence in Education*. Cham: Springer Nature Switzerland, 2025. Best paper nomination

🔥 LMs criteria recommendations can be problematic

LMs recommend additional criteria and recommendations,
Ie. audio support and avoiding effects

However, some recommendations hinder risks:

“Use of positive language and encouraging messages”
- Problem: patronizing if not related to learning processes

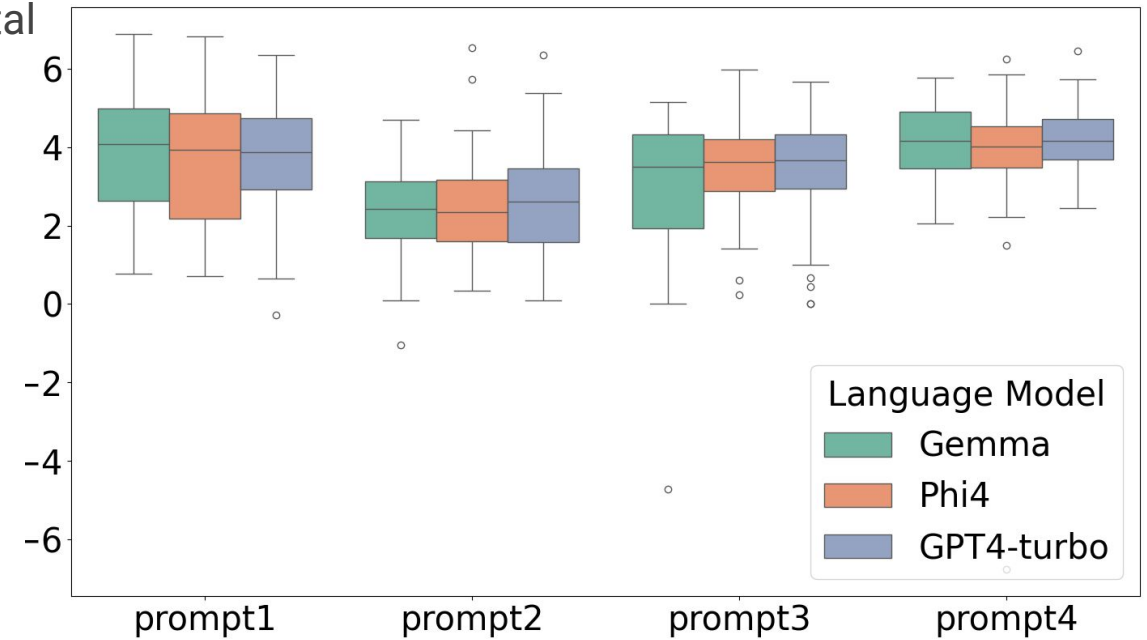
“Imagine you are reading the text from the perspective of someone with dyslexia”
- Problem: introduces labeling concerns and unintentional discrimination

Ilkou, Eleni, et al. "Dyslexia and AI: Do Language Models Align with Dyslexic Style Guide Criteria?." *International Conference on Artificial Intelligence in Education*. Cham: Springer Nature Switzerland, 2025. Best paper nomination

LMs improvements points over original text

GPT4-turbo: 100% of visual and 98% of content and total
Gemma: 96% of visual and 100% of content and total
Phi4: 100% of visual, content and total in Prompt 4

All prompts had significant improvements (normality Shapiro-Wilk test & stat. non-parametric Wilcoxon signed-rank test p<5%)



Ilkou, Eleni, et al. "Dyslexia and AI: Do Language Models Align with Dyslexic Style Guide Criteria?." *International Conference on Artificial Intelligence in Education*. Cham: Springer Nature Switzerland, 2025. Best paper nomination

Qualitative Analysis

"**butalso**" instead of "but also"
"**da**" instead of "the"

Gemma "[Topic]- **Easier to Read**"

GPT4-turbo deviated from its assigned task, and transitioned mid-response into an unprompted discourse on humanity and history in section "European Trading Communities in West Africa"

In five cases, the **GPT4-turbo** responses were initiated with proper context, however the body context raised concerns with **repetition of random words like gibberish**.
The sections were about:
- "The Rise of Slavery in the Chesapeake Bay Colonies",
- "European Contact with West Africa", and
- "Trans-Saharan Trade"

Ilkou, Eleni, et al. "Dyslexia and AI: Do Language Models Align with Dyslexic Style Guide Criteria?." *International Conference on Artificial Intelligence in Education*. Cham: Springer Nature Switzerland, 2025. Best paper nomination

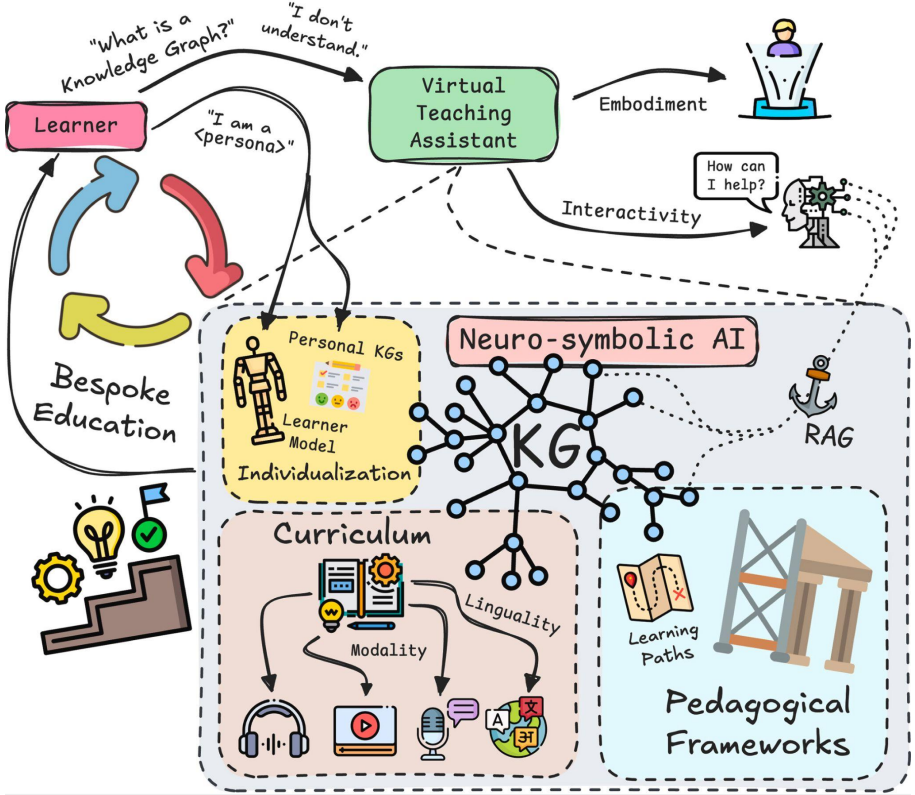
Future

Neurosymbolic Agents

Grounded in KGs
curricula, pedagogical frameworks, educational resources

Using LLMs for content generation and communication with the learner

Enabling
explainable, smart learning analytics, interpretation of complex human contexts, advanced problem-solving strategies, sophisticated and personalized decision-making on the agent



Jaldi, C. D., Ilkou, E., Schroeder, N., & Shimizu, C. (2025). Education in the era of Neurosymbolic AI. *Journal of Web Semantics*, *85*, 100857.

ORKG + TKG

Open Research KG
Scholarly
+
Teaching KG
Higher education
=

Smart Education

Ilkou, E.and S. Auer. Smart Learning Applications with the Combination of the Open Research Knowledge Graph and Teaching Knowledge Graphs. Zenodo, 2025, https://doi.org/10.5281/zenodo.16912917.

Research is a team work

Immediate projects at:

- Accessibility + GenAI content
- Domain modelling for higher education

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Stay in touch

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