



KnowCoder-V2: Deep Knowledge Analysis

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Abstract

Deep knowledge analysis tasks always involve the systematic extraction and association of knowledge from large volumes of data, followed by logical reasoning to discover insights. However, to solve such complex tasks, existing deep research frameworks face three major challenges: 1) Coarse knowledge management: They lack systematic organization and management of knowledge; 2) Inefficient Operation Manner: They operate purely online, making it inefficient for tasks that rely on shared and large-scale knowledge; 3) Shallow Knowledge Computation: They cannot perform complex knowledge computation, limiting their abilities to produce insightful analytical results. Motivated by these, in this paper, we propose a **Knowledgeable Deep Research (KDR)** framework that empowers deep research with deep knowledge analysis capability. Specifically, it introduces an independent knowledge organization phase to preprocess large-scale, domain-relevant data into systematic knowledge offline. Based on this knowledge, it extends deep research with an additional kind of reasoning steps that perform complex knowledge computation in an online manner. To enhance the abilities of LLMs to solve knowledge analysis tasks in the above framework, we further introduce **KNOWCODER-V2**, an LLM that bridges knowledge organization and reasoning via unified code generation. For knowledge organization, it generates instantiation code for predefined classes, transforming data into knowledge objects. For knowledge computation, it generates analysis code and executes on the above knowledge objects to obtain deep analysis results. Experimental results on more than thirty datasets across six knowledge analysis tasks demonstrate the effectiveness of KNOWCODER-V2. Moreover, when integrated into the KDR framework, KNOWCODER-V2 can generate high-quality reports with insightful analytical results compared to the mainstream deep research framework.

1 Introduction

Recently, Large Language Models (LLMs) have demonstrated remarkable capabilities in natural language understanding and generation (Zhao et al.). Through inference-time scaling, some LLMs, such as OpenAI-o1¹ and DeepSeek-R1 (Guo et al., 2025), allocate increased computational resources to generate longer chains of thought before producing responses, resulting in improved reasoning performance (Snell et al., 2024). These advancements have given rise to deep research, a new category of abilities to autonomously tackle complex tasks by searching and synthesizing information from diverse online sources (Li et al., 2025b).

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¹<https://openai.com/index/openai-o1-system-card/>

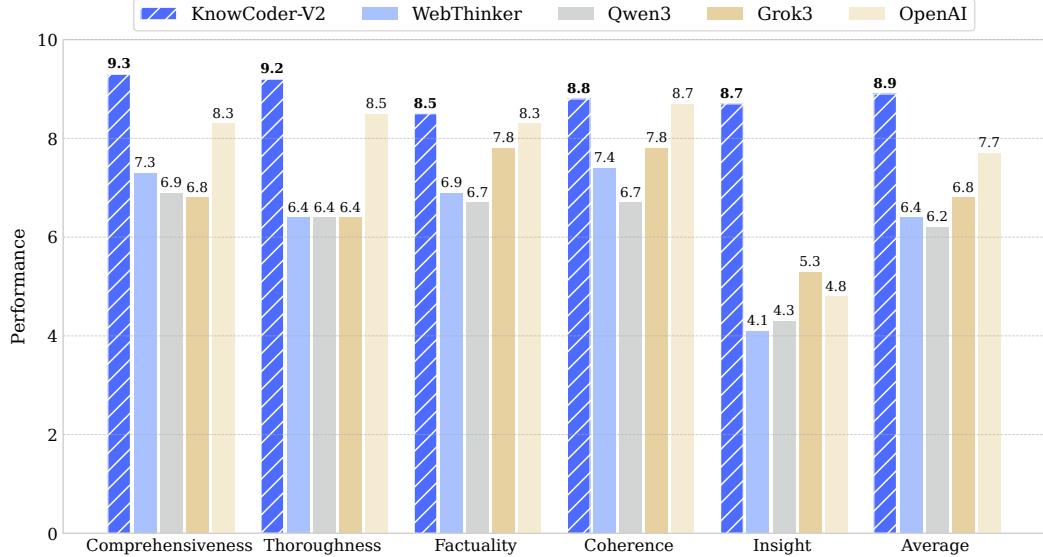


Figure 1: Report generation performance of the Knowledgeable Deep Research framework empowered by KnowCoder-V2 and its counterparts. Scores are averaged from DeepSeek-R1 and DeepSeek-V3 evaluations.

Although deep research framework shows considerable capability to handle several kinds of complex tasks, it falls short when dealing with one particular kind of tasks, which we refer to as deep knowledge analysis task. These tasks involve the systematic extraction, organization, and association of knowledge from large-scale and heterogeneous data sources, followed by multi-step logical reasoning over the such structured knowledge. For instance, the problem “What were the most influential research contributions to quantum computing between 2020 and 2024?” cannot be addressed through simple web search and text generation, especially when the analyses about the problem are not publicly available. Specifically, the limitations of the existing deep research framework can be categorized into three key dimensions:

- 1) **Coarse Knowledge Management:** The existing deep research framework search limited web pages to look up for information related to the task. In such frameworks, the basic unit of external knowledge is the web page. This results in coarse knowledge management, which means the models are hard to exploit fine-grained and organized knowledge distributed in thousands of documents.
- 2) **Inefficient Operation Manner:** The existing deep research framework operate entirely online, which may repeatedly searches and processes similar web pages across different tasks. This operation manner involves unnecessary computational overhead and hinders the efficiency of the framework.
- 3) **Shallow Knowledge Computation:** The existing deep research framework process text-form knowledge via text generation, which is only able to perform shallow knowledge computation. In contrast, deep knowledge analysis requires more sophisticated computational capability of knowledge, including aggregating information across entities and timestamps, performing logical deduction and statistical inference, and dynamically querying and transforming structured data. Without these capabilities, the deep research framework falls short of the depth and precision needed to support insightful analysis.

Motivated by these, in this paper, we propose a Knowledgeable Deep Research (KDR) framework that augments existing deep research systems with deep knowledge analysis capabilities. KDR contains two phases, i.e., knowledge organization and knowledge reasoning phase. In the knowledge organization phase, large-scale, domain-specific, and multi-source data are systematically preprocessed into structured knowledge based on a task-specific ontology. After this phase, we can obtain a structured knowledge base. In the knowledge reasoning phase, based on this organized knowledge base, KDR conducts complex knowledge computations in real time. Specifically, KDR further calls two kinds of reasoning steps to solve each subtask autonomously, i.e., deep computing step and

deep search step. The former aims to search for the structured knowledge and conduct complex computation to obtain the analysis results. The latter aims to search for the online website to get the related documents. With the two kinds of materials as input, KDR writes the final report.

To address the limitations of current LLMs in deep knowledge analysis tasks, we propose KNOWCODER-V2, an LLM that unifies knowledge organization and reasoning through code generation. In the knowledge organization phase, KNOWCODER-V2 generates instantiation code for predefined classes, systematically converting raw data into structured knowledge objects. In the reasoning phase, it produces analytical code that operates on these objects to perform complex computations and multi-step analysis. Experimental results on thirty datasets across six types of knowledge analysis tasks, including ontology expansion, knowledge extraction, and knowledge graph question answering, demonstrate the effectiveness of the proposed KNOWCODER-V2. Furthermore, by integrating KNOWCODER-V2, the proposed KDR framework can generate high-quality reports with comprehensive experimental analyses and deep insights.

In summary, our key contributions are from four aspects:

- We propose a knowledgeable deep research framework that empowers the existing deep research framework with deep knowledge analysis.
- To enhance the abilities of LLMs to solve the knowledge analysis tasks in the above framework, we introduce KNOWCODER-V2, an LLM that bridges knowledge organization and reasoning via unified code generation.
- Experimental results on more than thirty datasets across six knowledge analysis tasks demonstrate the effectiveness of the proposed KNOWCODER-V2.
- With KNOWCODER-V2, the proposed knowledgeable deep research framework can produce high-quality reports with deep analysis results.

In the following sections, we will first introduce the knowledgeable deep research framework in Section 3. Then, we will present the proposed KNOWCODER-V2 in Section 4. After that, we will evaluate the performance of KNOWCODER-V2 and the proposed framework in Section 5. Finally, we will conclude the paper in Section 6.

2 Related Work

2.1 LLM-based Knowledge Organization

For the knowledge organization phase, the related work primarily consists of three key tasks, i.e., ontology expansion, knowledge extraction, and knowledge update. Ontology expansion aims to involve integrating emerging new concepts into existing ontology structures by identifying their appropriate parents. Early works (Takeoka et al., 2021; Shen et al., 2024) fine-tuned BERT-based models to leverage textual descriptions of concepts and transfer this task into a multi-class classification task. Recently, some works (Moskvoretskii et al., 2024; Zeng et al., 2024) use LLMs to conduct this task and get significant improvement. Knowledge Extraction refers to leveraging LLMs to extract structured knowledge following the given concepts from the ontology, which can be divided into in-context learning (ICL)-based and supervised-based extraction. The ICL-based extraction Wang et al. (2023c); Li et al. (2023a); Guo et al. (2023) aims to leverage the universal capabilities of LLMs to extract the knowledge directly without fine-tuning the specific datasets. And Supervised-based Extraction Sainz et al. (2024); Li et al. (2024); Zuo et al. (2024) aims to construct a large IE corpus to fine-tune the LLM to better adapt to more specific domains or large-scale schema scenarios. Knowledge update refers to updating the out-of-date knowledge according to the given new extracted knowledge. The related techniques include entity linking, entity alignment, and so on.

2.2 LLM-based Knowledge Reasoning

The techniques related to the knowledge reasoning phase include Retrieval-Augmented Generation (RAG), Graph Retrieval-Augmented Generation (GraphRAG), Deep Research, and so on. RAG mitigates hallucinations by retrieving relevant documents as context for the LLM (Xu et al., 2024; Asai et al., 2023; Shao et al., 2023). GraphRAG extends this by extracting knowledge graphs from text

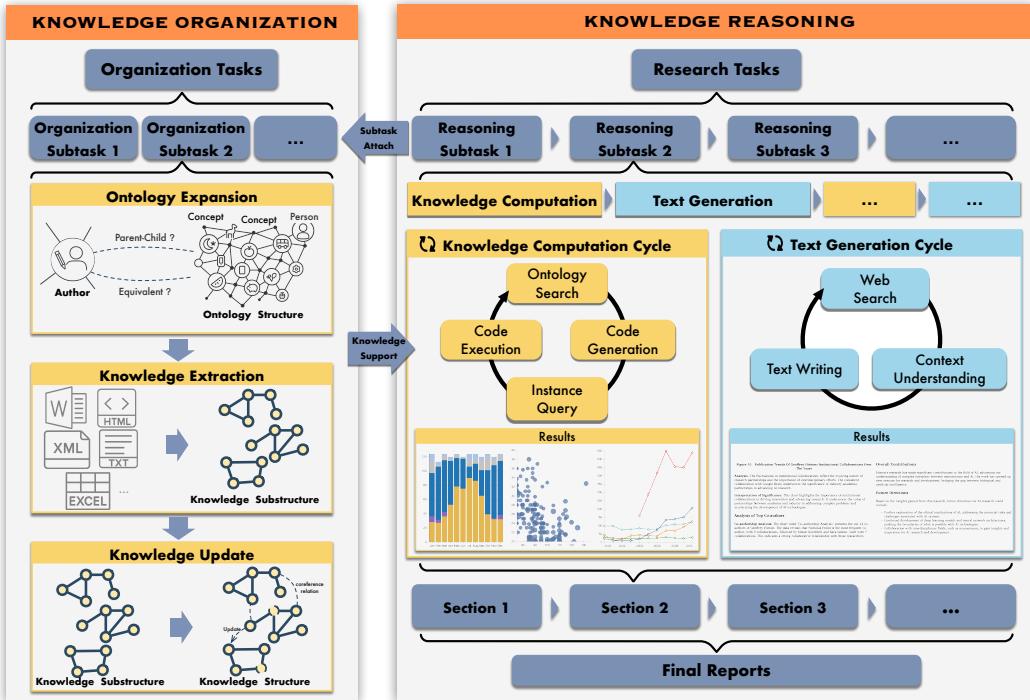


Figure 2: Demonstration of the proposed knowledgeable deep research framework. The mustard yellow blocks indicate tasks related to deep knowledge analysis, which includes knowledge organization and computation tasks.

and constructing community hierarchies, thereby improving the LLM’s comprehension of complex datasets (Edge et al., 2024; Ma et al., 2024).

Building on RAG, Deep Search or Deep Research further focuses on in-depth, multi-step investigation and analysis of information from diverse sources for deeper insights. This capability is commonly integrated as an advanced search feature in proprietary LLMs such as Sonar Reasoning Pro, and GPT-4o Search Preview. Works on open-source LLMs focus on augmenting reasoning for deep search. For instance, Search-01, ODS (Li et al., 2025a; Alzubi et al., 2025) augment the latest open-source reasoning LLMs by injecting the capabilities of web search tools to answer queries; others (Jin et al., 2025; Song et al., 2025; Chen et al., 2025) train LLMs with reinforcement learning to autonomously generate search queries during step-by-step reasoning. Besides, WebThinker (Li et al., 2025b) employs LLMs to autonomously search, explore web pages deeply, and draft research reports within its reasoning process. Agentic Reasoning Wu et al. (2025) enhances LLMs by integrating agents that utilize external tools and construct knowledge graphs for deductive reasoning. DeepResearcher (Zheng et al., 2025) focuses on training LLM agents in realistic web environments to perform iterative reasoning and search.

3 Knowledgeable Deep Research

In the following sections, we introduce the proposed Knowledgeable Deep Research (KDR) framework. As demonstrated in Figure 2, KDR distinguishes itself from traditional deep research framework by clearly separating knowledge organization into a dedicated offline phase. This decoupling allows the structured organization of vast amounts of research objects into accessible structured knowledge. Leveraging these structured knowledge, the KDR framework then enables rapid and in-depth analysis of research objects during the subsequent knowledge reasoning phase.

3.1 Knowledge Organization Phase

As shown in the left part of Figure 2, given a research topic as input, the offline knowledge organization phase first generates several organization subtasks, where each subtask corresponds to a concept that needs to be extracted. Then, for each subtask, this phase consists of three steps, i.e., ontology expansion, knowledge extraction, and knowledge update. First, in the ontology expansion step, KDR aligns the focused concepts to the existing ontology structure. Next, the knowledge extraction step transfers a large collection of related information into the corresponding structured knowledge. Finally, the knowledge update step updates the newly extracted knowledge into existing knowledge bases.

Task Decomposition. Given a research topic as input, the offline knowledge organization process first decomposes the overall task into several subtasks, each corresponding to specific research concepts such as entities and events. Entity concepts are associated with particular properties and relation types, while event concepts have defined argument types. For instance, considering the research question, "Please help me research the papers published by Geoffrey Hinton in the past decade and analyze the trends in his research interests over time", the related research entities would include academic papers along with properties such as publication date, authorship, citation and so on. Due to the critical role of this step, the process always employs a "human-in-the-loop" strategy: initially, LLMs propose the structures of concepts, which are subsequently reviewed and validated by human experts.

Ontology Expansion. As new organizational tasks emerge, concepts defined in these subtasks often have different labels but represent the same underlying meanings, or they may have associations with the existing concepts in the ontology. For instance, "author" is a subclass of "person" and is equivalent to the concept of "authors." To facilitate subsequent fusion of structured knowledge, the ontology expansion step systematically associates the new concepts with the existing ontology. Starting from the root concepts "Entity" and "Event," this step involves identifying both equivalence and hierarchical (hyponym) relationships among the concepts, ensuring consistency and semantic coherence within the ontology.

Knowledge Extraction. With the ontology as input, the extraction step processes various types of documents, including PDF, TXT, WORD, and HTML formats, to extract corresponding entities and events. This step can be formulated as the Information Extraction (IE) tasks Cowie & Lehnert (1996), specifically designed to derive structured knowledge from unstructured data. Typical IE subtasks performed here include Named Entity Recognition (NER), Relation Extraction (RE), and Event Extraction (EE).

Knowledge Update. Since knowledge is often dispersed across multiple documents, extracting information from a single document or text snippet usually provides only partial details about an entity or event. For example, assembling comprehensive data on a specific author's publications requires extracting relevant information from multiple sources, such as all their published papers. Additionally, knowledge can evolve over time. For instance, a person's residence might change. This step continuously updates the new extracted knowledge to previously extracted ones to ensure ongoing accuracy and consistency.

3.2 Knowledge Reasoning Phase

Given a specific research task, the knowledge reasoning phase generates a comprehensive report based on previously organized knowledge. As illustrated on the right side of Figure 2, this phase begins by decomposing the overall research task into multiple subtasks, each corresponding to a specific part of the final report. Each subtask is addressed through two types of reasoning steps, i.e., knowledge computation and text generation. Using the outputs from these reasoning steps, the complete and coherent research report is ultimately obtained.

Task Decomposition. This step decomposes the overall research task into several smaller reasoning subtasks. For each subtask, LLMs further adaptively carry out two distinct reasoning steps, i.e., knowledge computation and text generation, by generating the corresponding queries. Specifically,

the knowledge computation step retrieves structured knowledge from the knowledge organization phase and generate codes to conduct necessary computational analyses or experiments. The text generation step, on the other hand, involves retrieving and synthesizing information from online sources to support content generation.

Knowledge Computation Cycle. The knowledge computation cycle is automatically triggered when the corresponding queries are generated during the task decomposition step. Since knowledge computation involves large-scale data and thus cannot be included directly in the prompt, this reasoning step aims to generate the computation code based on the data ontology, rather than directly accessing the data. Specifically, it follows a cyclic process. In the ontology search step, it searches for the structures of relevant concepts and represents them in formats such as JSON, text, or code. Then, in the code generation step, code is generated based on the identified ontology structure. Following that, the instance query step retrieves instance data based on the ontology structure defined earlier. Finally, in the code execution step, the analysis code is executed on the retrieved instance data to generate the analysis results. If the code execution fails or the generated analysis results do not meet the required criteria, this cycle will be repeated until the desired results are achieved or the maximum number of iterations is reached.

Text Generation Cycle. The text generation cycle is automatically triggered when the corresponding queries are generated during the task decomposition step. This cycle searches for relevant information on the internet and uses it for subsequent text generation. Specifically, in the web search step, the system searches online websites using the decomposed query as input. Then, the LLM processes the retrieved websites and generates corresponding text. If the generated text does not sufficiently address the query, this cycle will be repeated until the desired results are achieved.

Merge and Revise. After the above two kinds of reasoning steps, the materials for a subtask are ready. Then, the merge and revise step will merge the materials to obtain the section content. Then, it will finally merge each section to form the complete report. Besides, an extra revision step is conducted to polish the report from a global perspective.

4 KnowCoder-V2

Although LLMs have demonstrated strong capabilities in many natural language processing tasks, they still face limitations when it comes to deep knowledge analysis. To address these challenges, we introduce KNOWCODER-V2, an LLM designed to bridge knowledge organization and reasoning through a unified code generation approach. In the following sections, we present the details of how KDR framework is implemented with KNOWCODER-V2.

4.1 Knowledge Organization Phase

The knowledge organization phase aims to systematically induce, extract, and update the structure knowledge related to the given research task. Following KNOWCODER-V1 (Li et al., 2024), we use Python classes to represent concepts in the ontology and Python objects to represent knowledge instances. As illustrated in the left side of Figure 3, two base classes, i.e., Entity and Event, are predefined. All other domain-specific concepts are implemented as subclasses of these base classes. For example, `class Person(Entity)`. The attributes of each concept (such as a person’s affiliation) are defined as member variables within the class. Additionally, examples and descriptions for each concept are provided in the class docstrings, consistent with KNOWCODER-V1.

4.1.1 Task Decomposition

Given a research task, we begin by decomposing it into a set of subtasks using a human-in-the-loop approach. First, the research task is provided as the input to an LLM, which infers the relevant concepts and their associated attributes. Next, these inferred concepts are manually reviewed to ensure accuracy and completeness. Finally, the validated concepts are automatically structured into Python classes.



Figure 3: Illustration of the Knowledgeable Deep Research Framework implemented by KNOWCODER-V2. We use DeepSeek-R1 to handle the parts of the KDR framework that are not related to knowledge analysis tasks.

4.1.2 Ontology Alignment: Class Relation Identification

The same concept may have different definitions across various knowledge organization tasks, and hierarchical relationships may exist between distinct concepts. This misalignment poses significant challenges for subsequent knowledge organization and reasoning. To address this, the ontology expansion step aims to identify semantic relations, including parent-child and equivalent relations, by analyzing the definitions of the corresponding concepts. To achieve this, we design a two-stage alignment process that combines pre-trained and large language models. In the first stage, following Zeng et al. (2024), SimCSE Gao et al. (2021) is adopted to encode the concept names and descriptions into m -dimensional vectors. Based on the cosine similarity among these vectors, we retrieve the top- k most similar candidate concepts. In the second stage, we refine the alignment results by prompting LLM with the code definitions of the candidate classes to determine whether they exhibit parent-child or equivalent relations.

4.1.3 Knowledge Extraction: Object Instantiation

In this step, KNOWCODER-V2 extracts the corresponding structured knowledge by instantiating the classes based on the given text. Previous work (Li et al., 2024; Wang et al., 2023b) requires

including all class definition code within the prompt. This presents a significant challenge: when a large number of concepts need to be extracted, the total class definition code can become excessively long and may even exceed the prompt length limit. As a result, both the effectiveness and efficiency of the extraction process can degrade due to the excessive length of prompts.

To address this issue, existing methods adopt a partitioned extraction strategy (Gui et al., 2024a; Liu et al., 2025). They divide the concepts into several groups and construct a separate prompt for each group, which are then processed individually by the LLMs to extract the corresponding knowledge. While this strategy can improve performance, it significantly reduces efficiency. In contrast, elegant code design does not require developers to repeatedly provide the full definition code for the same classes; instead, they can simply import the predefined classes. Motivated by this, we internalize class definitions into the parameters of KNOWCODER-V2, allowing it to use a simple import clause during the extraction process. To support these new capabilities, we introduce two types of training tasks, i.e., ontology understanding and following tasks to implicitly enhance KNOWCODER-V2’s ability to comprehend and operate on dynamic, large-scale knowledge organization tasks.

Ontology Understanding Tasks. To enable LLMs to understand the detailed definition of these classes, we define a ontology understanding task. After importing a class, we instruct LLMs to generate the detailed definitions with the prompt of “*Please generate the detailed schema of the class {type} from {task} based on your memory.*”

Ontology Following Tasks. Ontology following task aims to enhance the ability to follow the imported classes and generate instantiating code accordingly. It consists of two subtasks, i.e., class importing and object instantiate tasks. Given the text, class importing task aims to recall the corresponding types via completing the import clause. Given the text and import clause, object instantiate task aims to extract corresponding knowledge via generating the instantiating code. In some situations, users may predefine types that they want to extract but in other situations, the user may not give out the types explicitly and want the model to recall all the possible types in its memory. Thus, we conduct training under two settings, i.e., close domain and open domain settings. In the following, we will introduce details of the training data.

- **Class Importing Data.** In the closed-domain setting, users specify a predefined set of classes to be extracted. In this scenario, we begin by explicitly listing the relevant types using the import clause: *From {task} Import {type1}, {type2}*. Besides, we also give out the task description in the prompt: *Some {task} Types are imported above. Please instantiate all the possible {task} Objects in the following sentence.* . Then, KNOWCODER-V2 is instructed to recall the most potential types in the text. The output is the potential knowledge types in the form of *Import {type1}*.

In the open domain setting, we remove the given schema and only instruct LLM to recall possible types from knowledge types the model have learned by the task description: *According to the {task} Types you have learned, please import all the possible {task} Types in the sentence.* The output is potential knowledge types in the form of *Import {type1}*.

- **Object Instantiation Data.** After obtaining the potential knowledge types in the text, we aim to instantiate a concrete knowledge object by task description: *Some {task} Types are imported above. Please instantiate all the possible {task} Objects in the following sentence.* . The output is a list of instantiated objects same with direct extraction data.

4.1.4 Knowledge Update: Code Merge

In this step, KNOWCODER-V2 merges entities and events that share the same name. For these entities or events, their relations, properties, or arguments are combined into a single unified entity or event. Additionally, if previously stored knowledge conflicts with newly extracted knowledge, the system updates it with the latest knowledge. This heuristic strategy proves effective in most cases. Developing more precise and robust knowledge update mechanisms is left as future work.

4.2 Knowledge Reasoning Phase

In this section, we introduce the implementation details of the knowledge reasoning phase with KNOWCODER-V2.

4.2.1 Task Decomposition

As illustrated on the right side of Figure 3, the knowledge reasoning phase begins by decomposing the given research task into several subtasks. Each subtask addresses a research topic closely related to the research task. For each subtask, an LLM further decomposes it into two distinct reasoning steps, i.e., the knowledge computation cycle and the text generation cycle. Specifically, we use the tags `<begin_data_analysis>` and `<end_data_analysis>` to indicate the queries of the knowledge computation cycle and the tags `<begin_web_search>` and `<end_web_search>` to indicate the queries of the text generation cycle.

4.2.2 Knowledge Computation Cycle

Since various types of knowledge have already been encapsulated as distinct Python objects during the knowledge organization phase, KNOWCODER-V2 implements the knowledge computation cycle to generate executable code based on the queries derived from task decomposition. Specifically, this cycle produces three types of code: class definition code, knowledge declaration code, and knowledge computation code. By integrating and executing these components, KNOWCODER-V2 is able to perform deep and precise computations over the structured knowledge.

Ontology Search. Given a research subtask, the ontology search step aims to identify relevant concepts from the ontology. With the queries as input, we leverage Elasticsearch to retrieve code-based concepts that are most pertinent. Once identified, these concepts are then transformed into their corresponding class definition code, enabling seamless integration into subsequent knowledge computation processes.

Code Generation. Analysis tasks typically require large-scale data, making it impractical to include all the necessary data directly in the prompt. More importantly, when humans write code, they usually complete the entire script first and then input the data. Inspired by this manner, we assume the relevant objects has already been retrieved, instantiated, and stored in a variable named `search_results`. Consequently, KNOWCODER-V2 directly generates the code required to complete the corresponding queries based solely on the class definition obtained from the ontology search step.

Instance Query. In this step, we instantiate the corresponding entity objects and store them in the `search_results` list. First, we perform named entity recognition using an LLM to extract the topic entities of the queries. Next, using these extracted entity names, we use elasticsearch and entity names to query the knowledge base to find related entities. Finally, based on the subgraphs related to each entity, we instantiate the corresponding objects. Note that, if we query the knowledge base to find related entries. Finally, we instantiate the corresponding entity objects and store them in the list named `search_results`.

Code Execution. In this step, we integrate the class definition code, the filed `search_results` variables, and the analysis code to create the final executable script. By running this combined code in the Python execution environment, we obtain the corresponding analysis results. However, there could be situations where the code execution fails or produces incorrect results (e.g., generating empty charts). To address this, we incorporate an analysis evaluation agent that reviews the obtained analysis results and determines whether they satisfy the task requirements. If the results do not meet the specified criteria, the process loops back to the first step for corrections.

4.2.3 Text Generation Cycle

With the search query input, the model iteratively conduct web search until the query can be answered. Specifically, it contains three steps, i.e., web search, context understanding, and text writing. As these steps are broadly implemented in the existing deep research frameworks, we will not detail them in this paper.

4.2.4 Merge and Revise

A significant challenge is ensuring consistency between the results generated by the knowledge computation and text generation cycles. Inconsistencies often arise due to incomplete search re-

sults, quality issues in web content, or inadequacies in the structured knowledge. To address this, we designed an additional agent to merge results from both cycles and revise them. This agent autonomously evaluates the analysis results from the knowledge computation cycle alongside the generated results from the text generation cycle, identifies conflicting content, and resolves these discrepancies to achieve consistency.

4.3 Training of KnowCoder-V2

To enhance the extraction capabilities of KNOWCODER-V2, we utilized 14 Named Entity Recognition (NER) datasets, 7 Relation Extraction (RE) datasets, and 6 Event Extraction (EE) datasets, including three datasets in Chinese. Additionally, to further improve KNOWCODER-V2’s extraction capabilities, particularly its robustness, event extraction, and multilingual performance, we implemented data augmentation techniques described below.

For ontology alignment tasks in the knowledge organization phase and tasks in the knowledge reasoning phase, we are currently generating the corresponding training data and plan to release the trained models in the future.

Robustness Augmentation. To bolster the robustness of KNOWCODER-V2 against diverse inputs, we created an additional training corpus employing augmentation algorithms proposed by RobustUIE (Zhu et al., 2025). Moreover, to efficiently enhance robustness, we adopted a loss-guided data augmentation approach, selecting 20,000 informative samples from the augmented corpus for training.

Event Augmentation. We leveraged the English EE dataset EEMT (Liu et al., 2025) to strengthen KNOWCODER-V2’s fine-grained event extraction capabilities under extensive schema scenarios. Furthermore, to boost its Chinese event extraction performance, we developed a parallel Chinese version of the EEMT dataset.

Multilingual Augmentation. Considering the linguistic imbalance between Chinese and English datasets within the Information Extraction (IE) corpus, we employed the parallel data generation pipeline introduced by (Zuo et al., 2024). Using this method, we constructed parallel IE corpora from selected English datasets, aiming to facilitate knowledge sharing across languages and enhance Chinese information extraction performance.

KNOWCODER-V2 is fine-tuned based on the Qwen-2.5-Coder-14B-Instruct model (Hui et al., 2024), utilizing the LLaMA-Factory framework (Zheng et al., 2024). Parameter-efficient fine-tuning is achieved through Low-Rank Adaptation (LoRA) (Hu et al., 2021) with a LoRA rank of 32. The warm-up ratio is set at 0.01, and the learning rate at 3×10^{-4} . Sequence length is limited to 2048 tokens, and a batch size of 256 is used. During inference, the temperature parameter is fixed at 0. All training and evaluations are performed on eight NVIDIA A100 80GB GPUs.

5 Experiment

5.1 Tasks and Datasets

We evaluate KNOWCODER-V2 on two kinds of tasks, i.e., knowledge organization and knowledge reasoning tasks. For the knowledge organization task, We further evaluate the ontology expansion and knowledge extraction abilities on the corresponding datasets. For the ontology expansion datasets, we evaluate the performance on WordNet Sub-taxonomies from Bansal et al. (2014), Graphine taxonomies from Liu et al. (2021a), and three large-scale taxonomies from SemEval-2016 Bordea et al. (2016) across science, environment, and food domains. Table ?? presents the statistics of these taxonomies, all of which contain entities and definitions curated by human experts. For all benchmarks, we split the training and testing dataset following Zeng et al. (2024). For knowledge extraction, we choose 26 information extraction benchmarks under the supervised setting. For English IE, we evaluate performance across 10 benchmarks for NER, 6 benchmarks for RE, 3 benchmarks for ED, and 2 benchmarks for EAE. For Chinese IE, we evaluate performance on 2 benchmarks for NER, 1 benchmark for RE, 1 benchmark for ED, and 1 benchmark for EAE. Besides, we also evaluate KNOWCODER-V2 under the event extraction benchmark with massive types EEMT Liu

Model	SemEval-Sci		SemEval-Env		SemEval-Food		WordNet		Graphine	
	Acc	Wu&P	Acc	Wu&P	Acc	Wu&P	Acc	Wu&P	Acc	Wu&P
Self-supervised Setting										
TaxoExpan	27.8	57.6	11.1	54.8	27.6	54.2	19.8	64.8	24.5	65.9
STEAM	36.5	68.2	36.1	69.6	34.2	67.0	23.2	62.4	20.3	63.1
HEF	53.6	75.6	55.3	71.4	47.9	73.5	16.4	60.3	25.5	66.5
Musubu	44.9	76.2	45.3	65.4	42.3	72.4	28.5	64.0	35.4	75.2
TEMP	57.8	85.3	49.2	77.7	47.6	81.0	29.4	65.7	35.9	73.8
BoxTaxo	31.8	64.7	38.1	75.4	31.4	66.8	26.4	63.9	29.2	68.2
TaxoPrompt	61.4	85.6	57.4	83.6	53.2	83.1	40.3	71.5	33.9	74.4
TaxoInstruct	45.9	76.2	48.8	77.2	34.3	70.2	43.3	71.8	31.8	69.0
1-shot Setting										
NL (GPT-4o)	54.8	88.3	52.5	81.3	55.5	85.6	72.2	90.7	69.8	89.1
CodeTaxo (GPT-4o)	67.7	89.2	62.5	86.1	58.1	85.3	74.5	91.3	72.9	91.0
NL (GPT-4o-mini)	50.0	83.0	35.0	76.1	55.1	87.2	60.1	86.0	58.3	85.2
CodeTaxo (GPT-4o-mini)	58.1	85.6	42.5	76.0	55.9	85.3	68.8	89.2	61.5	85.1
KnowCoder-V2	59.7	80.8	62.5	88.2	60.2	87.6	76.9	91.4	83.3	95.9

Table 1: Performance on taxonomy expansion across five datasets. Metrics include Accuracy (Acc) and Wu&Palmer Similarity (Wu&P).

et al. (2025) and robustness benchmark RUIE Zhu et al. (2025). We use abbreviations from P1 to P14 for 14 kinds of perturbations defined in the RUIE. The detailed benchmark statistics are listed in Tables 2, 3. For the knowledge reasoning task, we further evaluate the Knowledge Base Question Answer (KBQA) and the report generation abilities. For the KBQA task, we adopt the most common dataset, WebQSP (Yu et al., 2023), as the dataset. For the report generation task, there are no suitable datasets. Thus we evaluate this abilities on the self-construct dataset about the scientific report.

5.2 Baselines

Knowledge Organization. For the knowledge organization task, we evaluate the performance of KNOWCODER-V2 on several kinds of tasks, including ontology expansion and knowledge extraction including entity extraction, relation extraction, and event extraction. For the ontology expansion task, we evaluated the performance of KNOWCODER-V2 against several baseline methods, including TaxoExpan (Shen et al., 2020), STEAM (Yu et al., 2020), HEF (Wang et al., 2022), Musubu (Takeoka et al., 2021), TEMP (Liu et al., 2021b), BoxTaxo (Jiang et al., 2023b), TaxoPrompt (Xu et al., 2022), TaxoInstruct (Shen et al., 2024), and CodeTaxo (Zeng et al., 2024).

For the knowledge extraction task, KNOWCODER-V2 is compared with the following universal IE baselines, including InstructUIE (Wang et al., 2023b), UniversalNER (Zhou et al., 2024), YAY-IUIE (Xiao et al., 2024), IEPILE (Gui et al., 2024b), B2NER (Yang et al., 2025), KnowCoder-V1 (Li et al., 2024), and KnowCoder-X (Zuo et al., 2024). Besides, we also introduce the mainstream LLMs such as Qwen series LLM (Hui et al., 2024), GPT series LLM (Achiam et al., 2023) in the robustness evaluation.

Knowledge Reasoning. For the knowledge reasoning phase, we first evaluate the performance of KNOWCODER-V2 on the KBQA (Knowledge Base Question Answering) task. For this task, KNOWCODER-V2 is compared with several baselines, including NSM (He et al., 2021), TIARA (Shu et al., 2022), DeCAF (Yu et al., 2023), KD-CoT (Wang et al., 2023a), StructGPT (Jiang et al., 2023a), KB-BINDER (Li et al., 2023b), Cot (Wei et al., 2022), ToG Sun et al. (2023) and G-Retriever He et al. (2024). Then, we evaluate the performance of the proposed knowledgeable deep research framework against the following baselines, i.e., Qwen3 Deep Research ², Grok3 Deep Research ³, OpenAI Deep Research ⁴ and WebThinker (Li et al., 2025b).

5.3 Results

5.3.1 Knowledge Organization

Results on Ontology Expansion. The results for ontology expansion are presented in Table 1. Compared to self-supervised methods, KNOWCODER-V2 outperforms all baselines on three benchmarks in terms of both accuracy and Wu&Palmer similarity. These results highlight the effectiveness of KNOWCODER-V2’s two-stage alignment phase, and show that its code-based definitions significantly enhance the model’s ability to analyze the corresponding concepts.

Model	NER											
	English						Chinese					
	ACE2005	AnaEM	Conll2003	BC2GM	BC5CDR	FindVehicle	MultiNerd	MIT Movie	MIT Restaurant	WikiAnn	MSRA	ResumenNER
Bert	87.3	85.8	92.4	80.9	85.3	87.1	91.3	88.8	81.0	70.6	95.0	95.9
InstructUIE	79.9	85.8	91.5	80.7	89.0	87.6	90.3	89.6	82.6	64.5	-	-
UniversalNER	86.7	88.7	93.3	82.4	88.7	98.3	93.7	90.2	82.4	84.9	-	-
YAYUIE	81.8	76.5	96.7	82.1	83.7	98.5	88.4	70.1	79.4	-	96.0	-
IEPICLE	81.9	81.9	92.5	80.7	88.1	98.5	94.6	88.2	79.9	72.6	88.0	93.9
B2NER	83.0	89.2	92.6	82.0	88.5	97.9	94.0	90.8	83.7	85.1	92.2	95.9
KnowCoder-V1	86.1	86.4	94.1	82.0	89.3	99.4	96.0	90.6	81.3	87.7	40.6	16.3
KnowCoder-X	87.5	89.2	94.7	84.5	88.5	99.5	95.9	89.5	82.0	84.5	96.0	96.1
KnowCoder-V2	87.8	90.0	95.0	85.9	90.8	99.5	96.0	93.3	82.1	86.1	94.0	96.2
												91.1

Table 2: The performance of all baselines and our models on NER.

Model	RE						ED				EAE							
	English			Chinese			Overall	English		Chinese		Overall	English		Chinese		Overall	
	ACE 2005	ADE corpus	Conll 2004	NYT	SciERC	Semeval RE		DUEE 2.0	Avg	ACE2005	CASIE	EEMT	DUEE1.0	Avg	ACE2005	CASIE	DUEE1.0	Avg
InstructUIE	-	82.3	78.5	93.0	43.5	58.5	-	-	-	43.2	67.8	-	-	-	56.8	63.5	-	-
YAYUIE	-	84.1	79.7	90.0	40.9	61.0	81.2	72.8	65.0	63.0	-	85.0	-	62.7	64.2	78.1	68.3	
IEPICLE	-	83.7	72.9	93.0	43.5	58.5	75.6	71.2	62.7	64.2	-	78.1	-	63.9	56.1	75.6	65.2	
KnowCoder-V1	64.5	84.3	73.3	93.7	37.4	58.5	20.4	61.7	74.2	58.2	9.1	15.9	39.4	70.3	20.8	7.9	33.0	
KnowCoder-X	-	84.5	73.1	96.1	44.9	64.8	82.9	-	-	73.6	63.9	-	87.2	-	70.0	65.0	82.1	72.3
KnowCoder-V2	66.3	85.0	73.3	96.1	47.3	67.2	83.1	74.0	75.3	67.1	53.5	87.1	70.7	71.2	65.2	81.4	72.6	

Table 3: The performance of all baselines and our models on the RE, ED and EAE tasks.

Results on Knowledge Extraction. The results for NER, RE, ED, and EAE tasks are shown in Tables 2, 3, respectively. Compared to KNOWCODER-V1, KNOWCODER-V2 significantly enhances extraction performance across all tasks and demonstrates strong adaptability to multilingual and multi-event scenarios. Besides, KNOWCODER-V2 outperforms the most advanced information extraction models on most benchmarks. In English IE, KNOWCODER-V2 has achieved a significant average improvement of 3.03% and 2.92% F1 on the NER, RE, ED, and EAE compared to all baselines. In Chinese IE, KNOWCODER-V2 surpasses the bilingual UIE baselines. Especially in domain-specific benchmarks such as BC2GM, BC5CDR, and SCIERC, KNOWCODER-V2 surpasses the current state-of-the-art by margins of 1.4%, 1.5%, and 4.3% points, respectively. This highlights KNOWCODER-V2’s capability in processing specialized knowledge, thereby offering compelling support for subsequent tasks. In the EEMT benchmark, where the type-recalling and partitioned extraction strategies are removed, KNOWCODER-V2 still demonstrates competitive extraction performance relative to LLM-PEE introduced by (Liu et al., 2025). Furthermore, compared to KNOWCODER-V1, KnowCoder-X (Zuo et al., 2024), and LLM-PEE, our method maintains comparable performance while significantly reducing the prompt length, thereby enhancing the overall extraction efficiency of the model. The results for NER, RE, and ED tasks under robustness settings are presented in Table 4. Compared to KNOWCODER-V1 and KnowCoder-7B-Robust, KNOWCODER-V2 demonstrates strong robustness across various perturbations and ranks 1st among all baselines with average of 78.6%, surpass the KnowCoder-7B-Robust by 1.4%. Notably, under more complex robustness setting such as Extended Sentence perturbation, KNOWCODER-V2 consistently maintains and or even improves its performance than None setting across all tasks (87.3% in P7 v.s 84.6% in None). This indicates that KNOWCODER-V2 is capable of handling longer and more complex texts while still delivering accurate knowledge organization.

5.3.2 Knowledge Reasoning.

²https://chat.qwen.ai/?inputFeature=deep_research

³<https://grok.com/>

⁴<https://chatgpt.com/>

Model	NER						RE						ED						Overall			
	None	P1	P2	P3	P4	P5	Drop _{avg}	None	P6	P7	P8	P9	Drop _{avg}	None	P10	P11	P12	P13	P14	Drop _{avg}	Avg	Rank
Open-source LLMs																						
Qwen2.5-14B-Instruct	58.6	53.6	57.7	55.0	56.9	46.6	7.9% _↓	22.6	19.2	21.3	17.1	8.8	26.5% _↓	32.0	29.8	30.4	30.9	31.4	32.0	3.4% _↓	35.5	12
Qwen2.5-7B-Instruct	53.3	49.8	51.2	50.5	51.2	41.3	8.4% _↓	15.6	13.4	14.0	13.8	3.8	27.9% _↓	19.0	18.8	17.6	17.9	18.8	19.2	2.8% _↓	27.6	14
Qwen2.5-3B-Instruct	49.5	47.5	46.7	45.3	45.5	40.2	9.0% _↓	8.9	7.6	8.6	7.4	2.0	28.1% _↓	13.3	13.8	12.3	12.6	12.7	13.6	2.3% _↓	22.8	16
Llama2-8B-Instruct	55.4	52.6	52.9	51.1	53.5	25.7	14.9% _↓	17.3	15.0	15.1	13.6	2.5	32.4% _↓	12.8	13.1	13.1	10.9	12.5	12.2	3.4% _↓	25.3	15
Glm-4-9B-Chat	57.4	54.0	55.8	51.4	56.6	43.2	9.0% _↓	8.8	7.5	7.5	7.4	1.8	31.2% _↓	5.6	6.6	4.7	4.1	5.1	5.9	5.7% _↓	22.6	17
Internlm2.5-7B-Chat	51.6	48.0	48.8	46.9	45.3	31.0	14.7% _↓	12.0	11.3	10.1	9.0	1.7	33.1% _↓	11.0	10.3	10.6	8.2	9.6	11.3	9.1% _↓	22.2	18
CodeLlama-7B-Instruct	46.3	45.0	45.0	38.9	42.4	14.5	19.7% _↓	13.7	11.6	12.2	11.3	2.8	30.8% _↓	8.6	9.3	8.8	6.1	8.2	9.2	3.3% _↓	19.6	19
Vicuna-7B-v1.5	39.0	38.2	37.4	35.0	38.0	16.7	15.2% _↓	11.2	11.0	10.1	7.6	0.8	34.1% _↓	6.9	7.5	7.2	4.5	6.1	6.3	8.4% _↓	16.7	20
Closed-source LLMs																						
GLM4-Plus	63.2	59.8	63.0	61.6	60.9	49.7	6.6% _↓	32.2	29.2	31.3	26.1	5.3	28.6% _↓	43.5	39.9	43.3	34.6	40.8	43.9	6.9% _↓	42.8	9
DeepSeek-V3	62.3	59.8	61.5	61.3	58.7	55.0	4.9% _↓	31.3	29.0	29.6	26.2	10.0	24.3% _↓	38.8	38.3	34.5	35.6	38.9	4.6% _↓	41.7	10	
GPT-4-turbo	60.0	57.5	59.8	58.2	56.2	33.4	12.5% _↓	33.0	30.0	31.6	26.8	4.5	29.6% _↓	40.0	38.0	39.6	34.5	37.3	39.8	5.4% _↓	40.0	11
GPT-3.5-turbo	51.8	47.9	48.9	50.5	39.0	33.1	15.3% _↓	23.8	20.6	21.3	16.7	2.4	35.9% _↓	38.0	29.5	36.1	36.7	33.9	36.9	8.9% _↓	33.3	13
Traditional IE Models																						
Stanza	80.7	70.1	77.1	71.5	78.1	51.1	13.8% _↓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
TNER	83.0	73.3	78.0	73.9	81.0	73.2	8.6% _↓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
PFN	-	-	-	-	-	-	-	76.3	58.6	73.8	68.4	20.4	27.5% _↓	-	-	-	-	-	-	-	-	
EEQA	-	-	-	-	-	-	-	-	-	-	-	-	-	68.3	53.2	64.0	63.4	59.7	66.5	10.1% _↓	-	-
UIE Models																						
UIE	83.9	74.3	81.1	75.6	81.7	70.3	8.7% _↓	84.1	63.3	81.1	77.0	35.9	23.5% _↓	71.3	52.6	65.2	67.7	67.6	68.8	9.9% _↓	70.7	6
InstrucUIE-11B	73.9	65.7	69.5	64.3	72.0	70.3	7.5% _↓	68.4	48.3	66.3	61.6	56.1	15.1% _↓	60.6	50.8	56.2	59.5	59.3	59.6	5.6% _↓	62.5	7
YAYI-UIE-13B	80.7	69.3	75.3	72.6	79.2	75.6	7.8% _↓	66.4	47.3	65.0	59.9	38.4	20.7% _↓	42.7	37.5	41.3	41.4	40.8	41.6	5.2% _↓	57.4	8
KnowCoder-7B	87.4	76.4	81.3	79.6	84.7	81.5	7.7% _↓	84.0	57.0	80.5	76.4	73.3	14.4% _↓	74.2	53.8	69.6	70.5	70.3	72.4	9.3% _↓	74.9	3
KnowCoder-7B _{partial}	84.4	73.8	80.1	81.1	82.1	79.0	6.1% _↓	81.4	60.6	79.1	74.5	52.8	18.0% _↓	69.1	55.5	66.1	65.8	66.8	67.8	6.8% _↓	71.8	5
KnowCoder-7B-Robust	85.9	81.3	83.5	86.4	86.1	84.6	1.7% _↓	83.1	66.0	82.9	81.1	79.8	6.8% _↓	70.2	65.7	67.1	70.5	68.3	69.6	2.8% _↓	77.2	2
KnowCoder-7B-RobustLDA	86.1	81.2	84.9	86.5	85.6	83.8	1.9% _↓	82.2	66.5	82.5	81.3	81.3	5.2%_↓	69.4	66.0	68.1	70.0	68.8	68.9	1.5% _↓	77.2	2
KNOWCODER-V2	87.4	81.7	83.9	87.9	84.9	84.0	2.4% _↓	84.6	65.8	87.3	81.9	78.8	5.6% _↓	74.7	74.6	70.8	72.9	72.9	69.5	3.7% _↓	78.6	1

Table 4: The performance of all baselines and our models on RUIE-bench.

Report Generation Task							
Method	Comp.	Thorough.	Fact.	Coherence	Insight	Avg.	
<i>Closed-source System</i>							
Qwen3 DeepResearch	6.9	6.4	6.7	6.7	4.3	6.2	
Grok3 DeeperSearch	6.8	6.4	7.8	7.8	5.3	6.8	
Openai DeepResearch	8.3	8.5	8.3	8.7	4.8	7.7	
<i>Open-source System</i>							
WebThinker	7.3	6.4	6.9	7.4	4.1	6.4	
KNOWCODER-V2	9.3	9.2	8.5	8.8	8.7	8.9	

Table 6: Performance on the report generation task.

Results on Knowledge Base Question Answering. Following ToG (Sun et al., 2023), we utilize the ground truth topic entity for each question. By centering on this topic entity, we extract the corresponding subgraph for each question. After converting the subgraph into class definition and instance code, KNOWCODER-V2 generates the analysis code based on the given questions. The Hits@1 scores for the KBQA task on WebQSP (Yu et al., 2023) are shown in Table 5. Compared to the fine-tuned baseline, KNOWCODER-V2 achieves a 2.6% improvement, even without any fine-tuning on the corresponding dataset. Additionally, when compared to prompting-based methods, KNOWCODER-V2 shows a 2.2% improvement. These results suggest that KNOWCODER-V2 is capable of generating accurate analysis code for the KBQA task.

Results on Report Generation. To evaluate the report generation ability of the proposed knowledgeable deep research framework empowered by KNOWCODER-V2, we construct a self-constructed dataset about the scientific report. The dataset focuses on researching the academic achievements about scientists and generate their corresponding reports. Following the setting in Li et al. (2025b), we use LLMs to give scores to reports generated by different methods from several aspects, including the completeness, thoroughness, factuality, coherence and an additional score called “insight”. The scores are averaged from two LLMs, including DeepSeek-V3 and DeepSeek-R1. The results are shown in Table 6. KNOWCODER-V2 achieves the highest score among all baselines on all metrics.

Method	WebQSP
<i>Fine-tuned</i>	
NSM (He et al., 2021)	74.3
TIARA (Shu et al., 2022)	75.2
DeCAF (Yu et al., 2023)	82.1
<i>Prompting</i>	
KD-CoT (Wang et al., 2023a)	73.7
StructGPT (Jiang et al., 2023a)	72.6
KB-BINDER (Li et al., 2023b)	74.4
CoT w. LLama2-70B-Chat	57.4
ToG-R w. LLama2-70B-Chat	68.9
ToG w. LLama2-70B-Chat	63.7
CoT w. GPT-4	67.3
ToG-R w. GPT-4	81.9
ToG w. GPT-4	82.6
G-Retriever	70.1
EdT w. ChatGPT	82.5
KNOWCODER-V2	84.7

Table 5: Performances of KNOWCODER-V2 on the KBQA task.

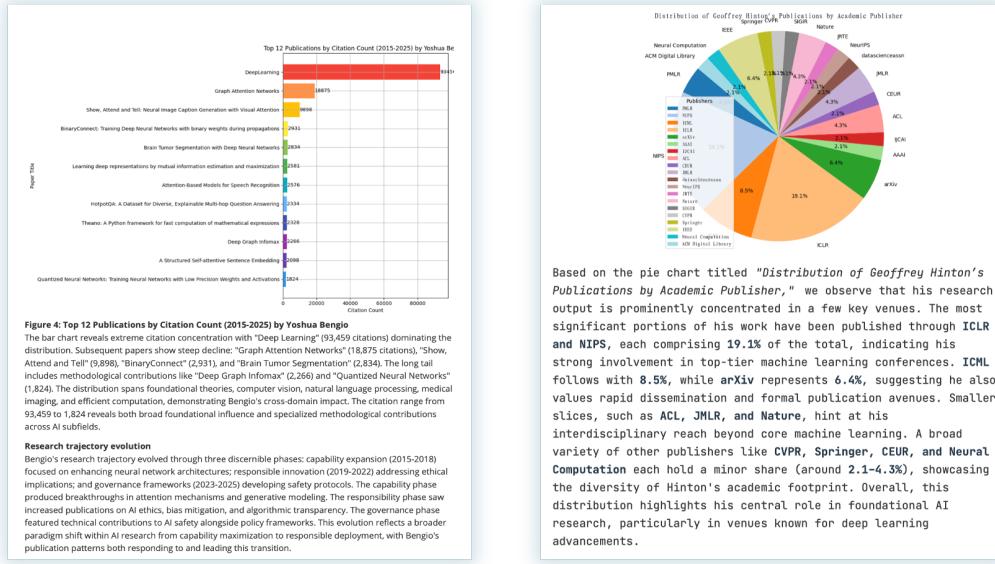


Figure 4: Two cases of reports generated by the KDR framework.

Due to the knowledge computation steps, KNOWCODER-V2 is able to generate more comprehensive and insightful experimental results and more deep analysis, leading to the significant improvement on “Insigt” score.

Case Study. To illustrate the depth of knowledge analysis that KDR can produce, we present two cases of partial reports generated by KNOWCODER-V2 under the KDR framework, based on the following queries: (1) "Search and summarize Geoffrey Hinton's research achievements in papers over the past decade (2015 to 2025), and generate a report," and (2) "Search and summarize Yoshua Bengio's research achievements in papers over the past decade (2015 to 2025), and generate a report." Based on the organized structured knowledge, the KDR framework automatically decomposes the research task and designs relevant experiments for KNOWCODER-V2. Leveraging the knowledge computation cycle, KNOWCODER-V2 can compute citation counts for Bengio's publications and visualize them in a chart. For Hinton, it can automatically analyze his publication preferences over the past decade and present the results in a pie chart. By analyzing these experimental results, KDR can identify each scientist's most influential academic contributions and their preferred publication venues. These analyses can offer novel, insightful findings rather than simply summarizing information already available online.

6 Conclusion

In this paper, we introduced the Knowledgeable Deep Research framework (KDR), which enhances traditional deep research frameworks by integrating advanced knowledge analysis capabilities. The framework features an independent knowledge organization phase that preprocesses large-scale, domain-specific data into systematic knowledge offline. This knowledge serves as the foundation for the framework’s online reasoning steps, enabling complex knowledge computations. We also presented KNOWCODER-V2, an LLM designed to perform deep knowledge analysis tasks through unified code generation. For knowledge organization tasks, KNOWCODER-V2 generates instantiation code to transform raw data into structured knowledge objects. For knowledge computation tasks, it generates analysis code that processes these objects to derive deep insights. Our extensive experiments across more than thirty benchmarks, spanning tasks such as ontology expansion, knowledge extraction, and knowledge base question answering, demonstrate the effectiveness of KNOWCODER-V2. Through KNOWCODER-V2, the KDR framework is capable of producing high-quality, in-depth reports with comprehensive analysis.

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