Research on the Innovative Development of Knowledge Services in Research Libraries in the AI for Science Era: Postprint

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Abstract

[Objective/Significance] AI for Science (AI4S) has exerted a revolutionary impact on various disciplines and research fields. This study explores the opportunities and challenges for the innovative development of knowledge services in research libraries in the AI4S era, as well as the response strategies for research libraries, aiming to provide references for knowledge service innovation in research libraries. [Method/Process] We review the conceptual origins and current research status of AI4S, discuss in depth the changes in the knowledge environment brought about by AI4S from the perspectives of knowledge subjects, knowledge processes, and knowledge tools, analyze the changes in the objectives, values, forms, and demands of knowledge services in research libraries, and propose response strategies for innovative development. [Result/Conclusion] In the AI4S era, research libraries should innovate and develop knowledge services from multiple dimensions. First, engage in cross-disciplinary collaboration and innovation to construct a diversified productive knowledge service system; second, cultivate smart librarians to stimulate an innovative environment; third, provide intelligent knowledge services based on large language models to achieve scenario innovation.

Full Text

Preamble

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Research on Knowledge Services Innovative Development in Research Libraries in the AI for Science Era
A Study on Knowledge Service Innovation in Research Libraries in the Age of AI4S

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Abstract: [Purpose/Significance] AI for Science (AI4S) has exerted revolutionary impacts across various disciplines and research fields. This study explores the opportunities and challenges for innovative development in knowledge services of research libraries in the AI4S era, as well as the coping strategies for research libraries, aiming to provide reference for knowledge service innovation in research libraries. [Method/Process] This paper reviews the conceptual origins and current research status of AI4S, discusses in depth the changes in the knowledge environment brought by AI4S from the perspectives of knowledge subjects, knowledge processes, and knowledge tools, analyzes the transformations in the objectives, values, forms, and demands of knowledge services in research libraries, and proposes strategies for innovative development. [Result/Conclusion] In the AI4S era, research libraries should innovate and develop knowledge services from multiple dimensions. First, engage in cross-boundary collaboration and innovation to build a diversified productive knowledge service system. Second, cultivate intelligent librarians to foster an innovative environment. Third, provide intelligent knowledge services based on large language models to achieve scenario-based innovation.

Keywords: AI for Science (AI4S); Large Language Model; Generative Artificial Intelligence; Knowledge Services; Research Libraries
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In recent years, the rapid development of Generative Artificial Intelligence (GAI) technology, particularly Large Language Models (LLM), has profoundly impacted various industries. In the field of scientific research, the swift advancement of generative AI technology has sparked an AI for Science (AI4S) boom [1]. AI for Science, also translatable as "AI-driven scientific research" and hereinafter abbreviated as "AI4S," represents the transformative influence of new-generation AI technology on scientific research. It marks a profound shift in research paradigms from data-driven to intelligence-driven approaches, heralded as the "fifth paradigm of scientific research" [2]. This transformation profoundly affects future learning and research models, posing new challenges to traditional knowledge services in libraries. Against the AI4S backdrop, how to integrate the powerful processing capabilities of large language models to achieve innovation in knowledge service models and provide precise, real-time knowledge services to meet users' complex needs has become a critical issue in the library and information science field. This paper aims to elucidate the connotation of the AI4S intelligent research paradigm and its impact on knowledge services, and to explore the innovative pathways and practical directions for knowledge services in research libraries.

1.1 AI4S Concept Origin and Research Status

Currently, AI4S practices are flourishing across various industries and fields, yet there remains some ambiguity regarding its conceptual connotation and terminological definition. The concept of AI4S was initially proposed by Academician E Weinan in 2018 [3] and gained widespread attention at the "2022 Zhongguancun Forum Series–First AI for Science Summit" hosted by the Beijing Institute for AI for Science in August 2022 [4]. The summit, themed "AI for Science: Co-creating the Future," released the first comprehensive report focusing on AI4S development, "2022 AI4S Global Development Observation and Outlook." In March 2023, the Ministry of Science and Technology, together with the National Natural Science Foundation of China, launched the special deployment work for "AI-driven Scientific Research (AI for Science)," laying out a frontier R&D system for AI-driven scientific research. In January 2024, the *Bulletin of Chinese Academy of Sciences* published a series of papers on AI4S. In this collection, Academician Li Guojie [2] proposed the concept of "AI4R (AI for Research)," arguing that compared to AI4S (translated as "scientific intelligence"), AI4R (translated as "intelligent research") encompasses broader content and deeper implications. While the former refers to AI-empowered research in science, intelligent research should not be limited to basic scientific research but should also include intelligent research in technology and engineering. Therefore, the term AI4R can more accurately describe this concept. Almost simultaneously, Qiu Zeqi from Peking University [5] published an article titled "The Future Vision of AI for Academia" in *People's Tribune · Academic Frontier*, arguing that academia comprises natural sciences, social sciences, and humanities (collectively referred to as sciences and humanities). He defined AI4S as "scientific intelligence for natural sciences" and used "AI for Academia" to describe "academic intelligence" that includes both "scientific intelligence" and "humanities intelligence."

Whether AI4S, AI4R, or AI for Academia, all reflect researchers' attention to AI empowering research across various disciplines. Although the term AI4R may have better referential clarity, AI4S is currently more widely accepted in academia and industry. In view of this, this paper adopts the term "AI for Science (AI4S)" and follows the broad concept of "science," considering AI4S as AI empowering scientific research in the broad sense, including basic science, technological science, and applied science. It is worth noting that before the term AI4S gained widespread recognition, research on intelligent scientific research had already been conducted. For example, Luo Wei et al. [6] used "intelligent scientist" in 2020, Hu Zhigang et al. [7] used "research intelligence" in 2021, and Sun Mengge et al. [8-9] used "intelligent research" to refer to the concept of AI4S. In fact, the application of artificial intelligence in scientific research can be traced back to the 1950s [10], but the concept of AI4S specifically refers to the transformative impact on scientific research paradigms after AI technology has developed to a certain stage. A landmark event was OpenAI's release of the generative AI tool ChatGPT in November 2022, which not only marked

the entry of AI into the large language model era but also further propelled AI4S into the spotlight. From the development history of AI4S, the ChatGPT explosion can be seen as a key catalyst for AI4S germination (marked by the first AI for Science Summit in August 2022).

AI4S has become a topic of common concern across multiple disciplines. In early 2023, scholars from different disciplines studied the nature of the AI4S research paradigm and its relationship with various fields from different perspectives. For example, Wang Shuyi et al. [11] discussed the opportunities and challenges that ChatGPT brings to researchers, Wang Feiyue et al. [12] explored the impact and significance of AI4S, and Zhang Xiaolin [13] examined the transformative effects of generative AI on knowledge services. Since then, research on AI4S has gradually increased, including studies on research paradigm revolutions in philosophy and science of science [14-15], discussions on constructing new paradigms for public governance in management [16], and explorations in practical fields such as intelligent scientific facilities [17], technology intelligence [18], and AI chemistry [19] in natural sciences. The 2024 Nobel Prizes in Physics and Chemistry both involved AI-related research, with the Physics Prize awarded to foundational research on artificial neural networks, reflecting the profound influence of AI in scientific research and providing new impetus for AI4S development worldwide.

1.2 AI4S and Knowledge Services

Since the outbreak of the ChatGPT technological revolution, the library and information science community has primarily focused on the macro-level field of information resource management to study the impacts of generative AI technology [20-22]. In 2023, Zhang Xiaolin [13] discussed the challenges that the ChatGPT revolution poses to knowledge services and possible responses, pointing out that for knowledge service practice, the transformation brought by ChatGPT is "a paradigm shift from ape to human." Since then, the library and information science community has conducted more in-depth discussions on the relationship between AI4S and knowledge services. Zhao Ruixue et al. [23] constructed a two-way empowerment mechanism and path between knowledge services and new quality productive forces by analyzing their internal and external connections. Zhang Xiaolin [24] explored the issue of finding new quality productive forces for knowledge services through AI-empowered P4ST (Policy for Science and Technology) decision intelligence analysis. Sun Tan et al. [25] argued that AI4S places higher demands on current knowledge services, including multi-level knowledge discovery and acquisition needs, interdisciplinary research and innovation needs, and user-centered participatory service needs, causing knowledge service scenarios to shift toward diversification, intelligence, specialization, and personalization. Zhang Zhixiong et al. [25] believed that the essence of AI lies in knowledge acquisition and utilization, while scientific literature is the primary carrier of human knowledge. They proposed the concept of building a knowledge base for scientific literature to serve AI4S, actively mining scientific knowledge

and high-quality data embedded in scientific literature, and transforming "scientific literature libraries" into "scientific knowledge engines" to support intelligent services required by AI4S, such as query-based evidence, situational awareness, reasoning and prediction, and generative insights.

Although academia has recognized that AI4S will have a profound impact on knowledge services, discussions on the essential connection between AI4S and knowledge services, particularly how research libraries should respond to the transformation of knowledge services, are still in the early exploratory stage. From the perspective of research libraries, this paper deeply analyzes the changes in the knowledge environment in the AI4S era and their impact on knowledge services, thereby providing insights for the innovative practice of knowledge services in research libraries.

2.1 Changes in Knowledge Subjects

In the AI4S era, changes in the knowledge environment are mainly reflected in the shift from a "digital knowledge environment" to a "digital-intelligent knowledge environment." The latter represents further development and evolution of the former, with the key difference being whether intelligent technology is used to enhance knowledge acquisition, processing, analysis, and application. Compared with the past, the most significant difference in the current digital-intelligent knowledge environment is that the subjects of knowledge creation have changed from humans alone to humans and intelligent agents. With the intellectual support of large language models, the ways and rates at which people solve problems will be significantly altered and improved. Consequently, the ways people interact with knowledge have also fundamentally changed. Large language models have replaced some intellectual activities previously performed by humans, such as information retrieval, integration, and summarization. Currently, AI capabilities continue to iterate and evolve.

In the traditional digital knowledge environment, when building information resource systems to support knowledge discovery (such as "science-ready" or "discovery-ready" systems) [26], the subjects of scientific discovery remained primarily human. Entering the AI4S era, the research focus has gradually shifted toward research infrastructure and knowledge systems adapted for AI (such as "AI-ready" systems) [27], where future large language models may possess scientific discovery capabilities to a certain extent. According to reports, Japan recently launched an AI system called "The AI Scientist," claimed to be "the world' s first AI system for automated scientific research and open-ended discovery." It is capable of handling the entire process from conceptualization, code writing, experiment execution, and result summarization to full paper writing, and can repeatedly conduct research processes iteratively to discover new research methods in an open-ended manner [28]. In the current era of human-AI interaction and symbiosis, knowledge sources have shifted from single human output to automated knowledge construction through human-machine collaboration, which will simultaneously promote the evolution of large language models

and the development of human knowledge, forming a two-way empowerment relationship.

2.2 Changes in Knowledge Processes

Some scholars believe that the research process itself is the research, rather than emphasizing the final paper or report [29]. This reflects the complexity of research processes and knowledge production. Changes in knowledge exchange and processing mechanisms cause fundamental shifts in knowledge production methods and significantly impact critical knowledge bottlenecks in research workflows, thereby prompting the emergence of new knowledge service mechanisms [26]. Knowledge processes involve learning, application, and creation, encompassing knowledge content, application contexts, and user communities. Therefore, knowledge services supporting knowledge processes should address these three dimensions; otherwise, they may weaken the effectiveness of knowledge services and even adversely affect knowledge learning, application, and creation.

In the print media era, difficulties in computing, associating, flexibly grouping, and interacting with knowledge content led to more rigid knowledge processes. The core change in the knowledge environment brought by the digital network era lies in supporting new knowledge processes—computational, dynamically associative, flexibly contextualized, and collaboratively interactive knowledge processes—thereby generating more demands and opportunities [30]. In the AI4S era, knowledge processes will undergo tremendous changes, primarily manifested in the deep integration of intelligence and automation, as well as the evolution of knowledge generation, reconstruction, and application models. Knowledge processes no longer rely solely on human cognition but gradually achieve human-machine collaboration, becoming more dynamic and intelligent. They can not only extract valuable information from massive data through technologies like natural language processing but also generate knowledge content and solutions in real-time according to users' specific needs. This new type of knowledge process provides a more efficient support environment for researchers and learners through large language models, intelligent computing, and real-time feedback.

Knowledge originates from users' research, learning, and management processes, presenting multiple forms and being exchanged through various mechanisms to form complex and intertwined knowledge systems. Academic publishing is only one mode of knowledge exchange. In the AI4S era, knowledge will become increasingly digital, rich-media, semantic, and intelligent, gradually pushing semantic publishing to become the norm. Knowledge products and tools are closely connected with knowledge learning, application, and creation, collectively forming a "Knowledge as a Service" platform. In this platform, computers will become new readers of knowledge publishing content, co-thinking and co-creating with users to solve problems.

2.3 Changes in Knowledge Tools

The AI4S era features an extremely rich array of knowledge tools. The combination of large language models and various AI tools is bringing profound transformations to knowledge generation, processing, and application, including automatic content summarization, knowledge graph construction, literature review writing, research hypothesis generation, task planning, and content review. AI agents can quickly plan complex tasks, test and evaluate their operability, engage in more exploratory research tasks, and drive innovation in professional services.

As a representative application field of AI4S, drug discovery has seen rapid development of new knowledge tools. The most well-known is AlphaFold [31], a protein structure prediction tool that has advanced human understanding of protein structures, accelerated drug target discovery, and profoundly impacted both biology and drug discovery. Molecular generation large models [32] can automatically generate novel compounds with specific properties by learning the relationship between molecular structures and properties. These tools, combining deep learning and generative models, can rapidly screen and optimize potential drug molecules. Additionally, Purdue University developed an AI platform for drug discovery experiments [33] that can interact with laboratory resources through natural language to plan and execute experimental workflows. This system helps scientists select the most suitable experimental resources and arrange instrument settings to accelerate scientific discovery. In digital publishing, publishers like Elsevier, leveraging their rich literature resources, are attempting to develop AI tools based on large models. Such AI tools possess capabilities similar to general-purpose large models like ChatGPT, enabling question-and-answer style extraction and summarization of publishers' literature resources. Since generated content is based on academic literature with clear provenance, these tools can provide more trustworthy content.

The evolution of research paradigms continuously shapes the knowledge environment. From the early data-driven and computation-driven e-Science era to today' s AI4S, each stage has brought changes in knowledge acquisition and application methods. In the e-Science era, the knowledge environment already exhibited characteristics of massive information and dynamic associations. Entering the AI4S era, the knowledge environment has become further intelligent, with high integration of data, tools, and technologies, providing researchers with more automated and precise support. Currently, almost all research tools are gradually incorporating AI functions, which will be combined in currently unpredictable ways to support research and innovation activities [34].

3.1 Impact on Library Knowledge Service Goals and Values

The breakthrough in AI technology enables knowledge services to achieve large-scale automation and personalized delivery, thereby unlocking new possibilities for knowledge service enhancement and becoming a new entry point for library

knowledge services [35]. In the long run, as AI technology continues to develop and mature, will knowledge services undergo "de-library-ization," or will AI empower library knowledge services to consolidate their position in the field? The key lies in how libraries clarify their positioning and respond to changing situations [35]. In the wave of AI development, how libraries can leverage their professional advantages in resource construction and user services to reasonably integrate AI technology and strengthen their authoritative position in knowledge services is an issue requiring special attention.

Although the knowledge environment will undergo significant transformation in the AI4S era, the core goal of library knowledge services—providing a knowledge creation environment for students and researchers—remains unchanged. Knowledge technologies, research methods, and tools are developing rapidly, making it difficult for researchers to keep track of all knowledge tools that could significantly enhance research efficiency while conducting research. This requires libraries to closely monitor the latest developments in research tools within their fields and promptly convey application methods and cutting-edge development trends to researchers and students through training and lectures.

As knowledge service institutions, libraries exist to meet users' service needs in knowledge discovery, application, and creation, with their value reflected in the support services provided for user needs. From a productivity perspective, users' processes of discovering, applying, and creating knowledge can be termed "user knowledge processes," and their capabilities can be called "user knowledge productivity." "Knowledge service productivity" can be viewed as the ability to help enhance "user knowledge productivity" within the "user knowledge process" [36]. In other words, libraries' fundamental task is to analyze and solve critical knowledge bottlenecks in the process of scientific and technological innovation from the user's perspective. The goal of library knowledge services is not simply to provide static knowledge products but to provide necessary environments and tools for the dynamic generation, reconstruction, and innovation of knowledge. In the AI4S era, re-establishing the goals and demands of knowledge services and clarifying the relationship between research libraries and knowledge service recipients are key to improving service effectiveness and user satisfaction.

Looking back at previous technological revolutions, libraries have always responded to new technology impacts with a positive attitude, actively adapting to and applying emerging technologies, continuously innovating their service models and capabilities, and ensuring the continuity and effectiveness of knowledge services. In the digital era, information internet technologies represented by Google did not replace library knowledge services. Instead, libraries provided solutions for specific teams' specific problems by embedding themselves in scientific and technological decision-making and research processes. In today's rapidly developing information and intelligence era, library knowledge services have become collaborative knowledge services supporting cooperative innovation, group learning, and interactive dissemination. Their goal has shifted to supporting users' dynamic knowledge needs, particularly continuous appli-

cations in research, education, and production. Libraries need to start from user needs, dynamically mine information resources through integration with AI tools, provide embedded comprehensive knowledge analysis services, explore problem solutions together with users, provide intelligent support for knowledge innovation, learning, and application, and enhance the value and influence of knowledge services.

3.2 Impact on Changes in Library Users' Knowledge Needs

Although the goal of providing knowledge creation for users remains unchanged, users' needs in research, learning, and daily life have already changed due to the transformation of the knowledge environment. Therefore, we should promptly identify these new knowledge needs and use them as the foundation for innovative development of library knowledge services.

From a research perspective, since the acquisition of simple knowledge has become easier and more convenient in the AI4S era, people hope to obtain dynamically organized results for their personalized workflows based on integrated multi-source resources, tools, and services. This is similar to how doctors and lawyers can organize different resources to solve specific diseases or litigation issues for clients. Although users' knowledge processes still require retrieval and acquisition of specific knowledge, they more urgently need an environment that integrates multi-source resources and capabilities for flexible interaction to explore, compute, and discover unknown knowledge. The extreme richness of knowledge tools and intelligent tools will give rise to new creative research tools and methods. Research libraries should actively explore and apply these tools and methods, work closely with researchers, and provide personalized services. Knowledge services should leverage large language models and generative AI to support researchers' creative work, especially in complex problem-solving and interdisciplinary knowledge fusion, continuously exploring the mechanisms of AI-empowered scientific research [13].

From a learning perspective, people have long realized that the purpose of learning is not merely "acquiring knowledge" but answering questions and solving problems through creative learning. However, only with the arrival of the AI4S era has this revolutionary transformation in learning methods become prominent, truly realizing this learning objective. Faced with AI' s powerful capabilities, learning content and methods urgently need to be re-examined. The accelerated speed of learning existing knowledge will inevitably accelerate the creation and iteration of new knowledge, which is both a challenge and an opportunity for knowledge services. Taking pharmaceutical knowledge learning as an example, today' s students can conveniently use large language models to learn compound structures, understand and predict their properties, and utilize advanced visualization methods to study drug-protein interactions. How librarians' roles should transform and what services should be provided to help researchers and students solve learning problems are new topics requiring urgent consideration and research. As a key technology in large language model

applications, prompt engineering has significant promoting effects on scientific research and learning. Currently, many research libraries have published prompt engineering guidelines to help students better utilize large models. For instance, Rice University' s Fondren Library held a workshop on "The Fundamentals of Prompt Engineering" [37] to help students learn how to interact effectively with ChatGPT, design prompts that maximize the use of large models, and covered practical application cases and templates. Carnegie Mellon University Libraries also offered an online workshop titled "Prompt Engineering for Research" [38] to introduce students to AI chat prompt usage skills and help them familiarize themselves with generative AI tools embedded in research databases.

From the perspective of information literacy and education, previous attention focused on cultivating new information literacy under digital research conditions, including information retrieval capabilities, information analysis capabilities, and data and knowledge management capabilities [26]. Now, the concept of information literacy has expanded to AI literacy [39], and how to creatively and reasonably use AI has been elevated to a very important position. However, AI development is a double-edged sword. While bringing convenience, it also makes issues such as intellectual property rights, knowledge governance, and research ethics increasingly prominent. Libraries must not only fully utilize AI' s creativity but also remain vigilant about potential risks like privacy and ethics and take appropriate preventive measures. This also places higher demands on AI literacy for library service personnel. It is foreseeable that library users will have more needs in these areas, requiring libraries to anticipate and agilely organize research teams to address these demands.

4.1 Cross-Boundary Collaboration and Innovation: Building a Diversified Productive Knowledge Service System

Knowledge service demands can be roughly divided into three levels: primary demand is direct need for information or knowledge products; intermediate demand is for knowledge-based capabilities (such as synthesis, reconstruction, analysis, diagnosis, and assessment); and advanced demand also includes using these capabilities to build various service chains and value chains supporting knowledge production processes [36]. With increasingly complex social division of labor, the challenge for research libraries is how to optimize resource allocation and enhance innovation support capabilities through knowledge services. Traditional knowledge services mainly focused on providing information and knowledge products, but in the AI4S environment, libraries should shift toward supporting users' knowledge production processes through knowledge processing capabilities, building a flexible and diversified productive knowledge service system. This can not only help users solve specific problems but also promote scientific and technological innovation and industrial progress.

In the AI4S era, the widespread application of generative AI has promoted integration across different industries, disciplines, and departments, gradually dissolving existing boundaries and injecting new development momentum into

knowledge service innovation in research libraries. Cross-boundary integration has not only become a new trend in smart library development but also provided opportunities for reshaping their roles in knowledge production and services. For example, the "Smart Library + Publisher" model achieves resource circulation and sharing between smart libraries and publishing institutions. Smart libraries can obtain the latest data resources and academic research results in the first instance to enrich their collection resources and provide users with more convenient resource access channels. Meanwhile, publishers can enhance the exposure and social recognition of academic achievements through libraries' user networks, forming a virtuous cycle of resource sharing and mutual benefit. In the "Smart Library + Data Supplier" model, smart libraries can access richer and more professional data resources, thereby providing precise resource services to meet users' needs across various disciplines. This cooperation can further enhance libraries' capabilities in data resource integration and optimization, enabling libraries to achieve leapfrog development in service depth and data coverage breadth. Additionally, the "Smart Library + Educational Institution" model builds a learning ecosystem combining resources and teaching. Educational institutions rely on smart libraries' rich collection resources and information services to enrich curriculum resources and learning projects, while libraries leverage educational institutions' professional faculty to provide users with personalized and specialized learning guidance services. This model can not only create efficient and open learning environments for students and researchers but also enhance libraries' core value in knowledge innovation and dissemination.

Cross-boundary collaboration and innovation are not limited to integrating libraries with external resources but can also create diversified service ecosystems through internal cross-departmental collaboration within libraries' host institutions. For example, libraries can collaborate with IT departments and data science teams to explore deep applications of generative AI, or cooperate with academic institutions and research centers to develop personalized knowledge service solutions for research users. Through these cross-boundary collaborations, smart libraries can continuously innovate in knowledge services and resource provision, fully leverage the advantages of generative AI technology, create more open, inclusive, and diverse knowledge ecosystems for users, and achieve win-win cooperation among multiple parties.

4.2 Cultivating Intelligent Librarians and Fostering an Innovative Environment

In the AI4S era, the development of smart libraries requires not only the introduction of advanced technology but also the active participation of professional librarians and the cultivation of their intelligent service capabilities. Intelligent librarians play a crucial role in knowledge service innovation. They are not only important forces driving new technology applications but also key players in resource integration and user services. Research indicates that based on their professional knowledge and deep understanding of library business processes,

intelligent librarians can create business scenarios and service models that AI companies can hardly foresee by guiding and applying generative AI technology, opening up more possible application areas for generative AI in libraries [40].

The core of cultivating intelligent librarians lies in enhancing librarians' digital literacy and technology application capabilities, ensuring they can proficiently master and innovatively apply generative AI technology to foster an innovative environment. To this end, libraries can regularly organize generative AI technology training courses and thematic seminars to help librarians understand and master the basic principles and operational procedures of generative AI applications. On this basis, advanced technology courses should be provided to enable librarians to independently explore and practice innovative applications of generative AI technology in library services. Meanwhile, creative laboratories or innovation workshops should be created to provide librarians with low-risk free exploration environments, encouraging them to propose new application ideas, test new business scenarios, gradually optimize application feasibility and user experience, and attempt cross-boundary service models. Finally, an innovation culture should be fostered through incentive mechanisms, establishing innovation awards, providing resource support or promotion opportunities, and creating a positive innovation atmosphere to ensure librarians feel continuous motivation for innovation in their daily work.

As practitioners of the "smart library" concept and guides for technology application, intelligent librarians will play an increasingly important role in future knowledge service innovation. By enhancing intelligent librarians' professional skills and innovative awareness, libraries can achieve more long-term development in the application of generative AI. This will not only improve the quality and efficiency of knowledge services but also drive the intelligent transformation of the entire library industry.

4.3 Providing Intelligent Knowledge Services and Achieving Scenario-Based Innovation

In terms of specific practice, with the development of large language model technology, knowledge services in research libraries are undergoing a transformation from static information provision to dynamic intelligent services. In the AI4S era, libraries need not only to enhance services with AI tools like large language models but also to achieve scenario-based innovation to better meet the complex and diverse needs of research users, thereby transforming into providers of intelligent knowledge services. The core of intelligent knowledge services lies in using AI models and computational methods to identify and solve users' problems in specific scenarios, thereby generating knowledge increments for users during problem-solving. For example, by applying large language model tools, libraries can provide more interactive and intelligent services instead of merely offering static knowledge resources. By designing specialized models for different research fields and application scenarios [32], libraries can use these AI tools to provide users with personalized and intelligent solutions. This "Model as a

Service (MaaS)" concept can not only expand libraries' service capabilities but also flexibly respond to the constantly changing demands in research activities.

The true realization of intelligent knowledge services requires the drive of scenario-based innovation. Libraries need to deeply understand users' specific research and application scenarios to better provide intelligent knowledge services. For instance, libraries need not only to understand users' knowledge needs but also to combine specific research processes and scenarios to design intelligent solutions using large language model technology. In this process, libraries' collection resources can also be further optimized through integration with large language models. Libraries should not only re-evaluate and utilize existing resources but also combine these resources with large language models to form a knowledge support system covering all scales, modalities, and granularities. For example, libraries can use AI tools to transform collection resources into computable large-scale knowledge bases [41], enabling these resources to be efficiently processed and analyzed by large language models, thereby providing users with deeper research support. The ultimate goal of intelligent knowledge services is to make knowledge creation, learning, and application an active, interactive, exploratory, and constructive process. In this process, libraries provide systematic support for users in exploring knowledge gaps and anomalies and solving specific problems through intelligent interaction and model computation, forming an integrated knowledge service chain from data to wisdom.

Existing research has begun to explore the application of large language models in book resource recommendation, information literacy teaching material development, and automated reference consultation, achieving preliminary results. For example, research has applied large language model technology to book resource understanding and recommendation by constructing a BookGPT framework based on ChatGPT [42]. BookGPT can provide more accurate recommendations in multiple scenarios, including book rating, personalized user recommendation, and content summary generation. It can also generate personalized content based on users' interest preferences and identity information, providing users with more suitable book selections and more intuitive content overviews. This intelligent recommendation service can effectively save users' time in finding resources and enhance their experience in library knowledge service scenarios. Other research has explored ChatGPT' s application potential in information literacy teaching material development. By using publicly licensed resources and customized chatbots, it not only reduces the time and cost of content development but also enables efficient querying of specific literature resources [43]. This teaching material generation model provides an innovative practical path for library information services, helping to solve problems of high cost and long cycles in traditional teaching material development. In library reference consultation, ChatGPT-like AI systems can provide "24/7" uninterrupted reference services. Although current systems still have considerable room for improvement in answer accuracy [44-45], it is believed that with technological progress, these systems will play important roles in future intelligent

knowledge services. Recently, China' s DeepSeek has become wildly popular, leading lower-cost deployment of deep reasoning capability large model technology. Major institutions at home and abroad have connected to DeepSeek to explore its applications in intelligent Q&A, text generation, and data analysis. In the future, research libraries may embed their collection resources into DeepSeek technology to optimize digital resource management and knowledge service systems and explore more scenario-based innovative development.

In the AI4S era, the models of scientific discovery and knowledge production will undergo significant changes, and consequently, the forms of knowledge services also face important transformations. Research libraries should actively consider their positioning and seek strategies for innovative development. Specifically, research libraries need to clarify the core and competitiveness of knowledge services, engage in cross-boundary collaboration with other entities in the knowledge service ecosystem, cultivate the innovative capabilities of intelligent librarians, provide intelligent knowledge services and scenario-based innovation through large language models, and continuously expand service boundaries. Only in this way can libraries play a key role in the constantly changing research environment and provide strong support for users' knowledge creation and application.

This paper' s discussion on knowledge service innovation in research libraries in the AI4S era also has certain limitations. First, although it explores the transformation direction of knowledge services in research libraries under the AI4S background, more empirical cases are still needed to verify the practical feasibility of these innovative strategies. Second, current large language models still face many challenges in organizing and applying scientific knowledge, such as data quality, model bias, and knowledge traceability, which may affect their application effectiveness in library knowledge services. Finally, libraries also need to consider contextual factors such as organizational culture, technical infrastructure, and user acceptance when promoting knowledge service innovation. Future research can conduct more detailed investigations and analyses in these areas to further explore the intelligent transformation path of research libraries in the AI4S era.

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Note: Figure translations are in progress. See original paper for figures.