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How does Logical Dynamics assist interdisciplinary education and research in addressing cognitive challenges?

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ABSTRACT

In today's rapidly changing and challenging world, complex interdisciplinary issues continue to emerge, such as environmental sustainability and artificial intelligence-driven adaptive learning. Understanding and resolving these problems require individuals to integrate knowledge, methodologies, and diverse ways of thinking. Within this problem-oriented process, the importance and potential necessity of interdisciplinary education and research become self-evident. However, how can we better promote interdisciplinary communication in the sense of transdisciplinary notions? This is a systematic endeavor involving multiple aspects, including cognition, methodology, team collaboration, and policy formulation. This paper focuses primarily on the cognitive level, first conducting an in-depth analysis of the cognitive challenges faced during interdisciplinary cooperation and communication. In response to these challenges, the paper introduces Logical Dynamics (a theoretical framework) and Dynamic Epistemic Logic (a formal tool). From three dimensions—perspective transformation, cognitive representation, and educational application—the article elaborates on "how Logical Dynamics provides guidance for interdisciplinary education and research at the level of cognitive thinking."Moreover, artificial intelligence has been deeply integrated into interdisciplinary communication. Under the guidance of Logical Dynamics, AI can more accurately articulate problems and facilitate the generation of more creative solutions among interdisciplinary participants.

Keywords: Interdisciplinary communication, Research, Education, Logical dynamics, Dynamic epistemic logic, Cognitive abilities, Artificial intelligence

1. INTRODUCTION

Why can this paper be said to address interdisciplinary research and education from the perspective of a transdisciplinary notion through logical dynamics?

When analyzing the challenges faced by interdisciplinary research, we primarily focus on cognitive challenges, which involve various types of thinking skills such as critical thinking, reflective thinking, etc. These skills are essential for both interdisciplinary and transdisciplinary research. In response to these challenges, we have chosen logical dynamics, which is not only a systematic theory but also includes formal methods. Moreover, to some extent, it represents a higher-level holistic understanding, thus possessing characteristics of transdisciplinarity. Therefore, while using logical dynamics to help interdisciplinary research meet cognitive challenges, it inherently carries a higher-dimensional understanding and a global open perspective. Hence, in this sense, this paper addresses the cognitive challenges faced by interdisciplinary research and education from the perspective of a transdisciplinary notion through logical dynamics. After all, although interdisciplinary cooperation in academic research requires verification of feasibility, the minds of researchers have never been confined by boundaries. At the same time, this paper believes that the goals of research and education differ; the core of research lies in academic development, while the core of education lies in nurturing individuals.

This article directly aligns with the goals of "Interdisciplinary Communication on Trans-Disciplinary Notions," offering a systematic and structured approach to initiate and sustain meaningful dialogues across disciplines while addressing the challenges of trans-disciplinary collaboration.

2. THE IMPORTANCE OF INTERDISCIPLINARY RESEARCH AND EDUCATION

There are various interpretations regarding the definitions of interdisciplinary research and education. Here, we focus on understanding that is based primarily on the following two descriptions. Interdisciplinary research generally refers to "a research model conducted by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or specialized knowledge systems in order to enhance understanding or address issues beyond the scope of a single discipline's research domain"

[1]. On the other hand, interdisciplinary education aims to assist students in building 'cognitive bridges' between disciplines, enabling them to flexibly apply knowledge from multiple disciplines and form multidimensional cognitive frameworks [2].

From these definitions, we can understand the connection between the two: the former is essentially an innovative process of knowledge production and application, focusing on "problem-solving"; whereas the latter places greater emphasis on "cultivating individuals capable of solving problems," involving the development of various interdisciplinary skills. In the mutually reinforcing process, they form a positive feedback loop, thereby serving the needs of complex societies.

Currently, the academic research field is facing many complex, systematic, and sustainability-related topics. Moreover, the development of most single disciplines has encountered bottlenecks, while the differences between various disciplines provide new ideas for solving these problems because knowledge and methods from different disciplines may help understand and solve problems in other fields. For instance, using computers to analyze gene sequences in the emerging interdisciplinary field of bioinformatics. It is precisely because interdisciplinary research and education organically integrate theories, methods, and practices from natural sciences, social sciences, and humanities [3][4] that they not only help people better understand complex issues but also, more encouragingly, contribute to finding new ways to solve these problems [5].

At the same time, in terms of education and teaching, the urgent needs of 21st-century social development call for innovative talents with intercultural competence, critical thinking, creative problem-solving skills, communication and collaboration abilities, as well as a sense of social responsibility [6]. This aligns perfectly with the goals of interdisciplinary education. Through interdisciplinary education, it is possible to help people find "ways to combine scientific, technological, engineering, and mathematical research with interests and concerns about human affairs, welfare, values, or culture" [7]. Meanwhile, interdisciplinary education emphasizes the cross-disciplinary connections between different fields, which can effectively reduce phenomena such as subject bias, including the current issues of one-sided education and underrepresentation of humanities and social sciences [8], helping individuals broaden their horizons and continuously adapt to solving complex social problems.

3. THE COGNITIVE CHALLENGES FACED IN INTERDISCIPLINARY COMMUNICATION AND COOPERATION

However, coexisting with the value of interdisciplinary communication and cooperation are also multiple challenges, here we mainly refer to cognitive challenges.Consider this question: Do researchers already know how to engage in interdisciplinary communication and cooperation when they enter an interdisciplinary research project? Have they automatically acquired the necessary skills for interdisciplinary collaboration? Both theoretical research and practical data indicate that the outcome of this question is not optimistic [5][9].

Critical thinking, reflective thinking, systems thinking, the ability to synthesize and integrate knowledge, communication and collaboration skills, etc., are all essential cognitive abilities for interdisciplinary researchers. In particular, critical thinking and reflective thinking directly correspond to the cognitive dimension of interdisciplinary communication—“seeking conceptual commonalities”[10][11]. This is crucial for interdisciplinary communication because interactions between different disciplines face high levels of complexity, uncertainty, and conceptual ambiguity.

The lack of interdisciplinary thinking skills among researchers can lead to difficulties in finding conceptual commonalities during interdisciplinary communication, resulting in a failure to achieve deep understanding. Consequently, research practices aimed at "comprehensive interdisciplinarity" may degenerate into "additive multidisciplinarity" projects [5], meaning that they merely represent the accumulation of multiple disciplines without generating valuable connections or interactions.

This prompts us to reflect deeply: Does higher education cultivate interdisciplinary thinking among prospective educators and researchers? Is this education sufficient to enable doctors in the future to smoothly participate in interdisciplinary research and correctly guide students in engaging in interdisciplinary communication? The reality is that doctoral education often focuses on specific disciplinary subjects and working methods, with insufficient emphasis on education for interdisciplinary communication and cooperation [12]. To meet the intellectual challenges, we need systematic theoretical guidance and educational practices in interdisciplinary studies so that doctoral candidates can understand interdisciplinary research capabilities and identify with their roles as interdisciplinary scholars. At the same time, doctoral students themselves also exhibit a strong willingness for interdisciplinary collaboration; they mention that these experiences can enhance their ability to work across multiple disciplines and lay a solid foundation for replicable principles of interdisciplinary learning [12].

So, how can we effectively assist researchers from different disciplinary backgrounds to participate in this interdisciplinary communication right from the start? This requires guidance at the level of cognitive thinking, where logic can serve as an important tool. First, we need some clarification on the "view of logic". What is referred to here goes beyond static logical rules; more importantly, it involves dynamic theories and tools of logical interaction.

4. THE KEY TO THOUGHT: LOGICAL DYNAMICS AND DYNAMIC EPISTEMIC LOGIC

Logic is the immune system of the mind.
—— Johan van Benthem, renowned logician

The logic familiar to people concerns static rules and conclusions about concepts, judgments, reasoning, or proofs, which form a rational defense for human cognition and thought. Equally significant as these logical conclusions is the process of mental interaction involving "posing questions and providing answers," which corresponds to what Johan van Benthem referred to as the "dynamic turn" in logic in his 1991 work *Language in Action* [13]. Then, in 1996, in *Exploring Logical Dynamics*, he continued and deepened this perspective [14], referring to it as Logical Dynamics: "This is a general theory concerning agents who generate, transform, and transmit information; during this process, the social interactions among agents are just as important as individual capabilities." [15]

"Logical Dynamics" employs the framework of Dynamic epistemic logic to present a rich panorama of the cognitive process, showcasing belief revision and agent interaction, thereby continuously creating conditions for the revelation of truth and providing a clear perspective on agents' understanding of their cognitive abilities. Based on this, it will help agents autonomously construct a more complete cognitive system and thinking ability. Dynamic epistemic logic is not only a systematic and structured theoretical framework but also an important formal tool when studying the foundations of cognitive behavior [16]. It is based on Kripke's possible-world semantics, used to describe states, actions, and events in the cognitive processes of agents, and through semantic interpretation and rules, it characterizes dynamic processes in cognitive interactions such as belief revision, knowledge updating, and preference changes. Meanwhile, this framework is flexible and extensible, adaptable to complex social scenarios.

Indeed, as demonstrated by the affirmation of van Benthem regarding the relationship between logical dynamics and interdisciplinary communication, the two mutually reinforce each other, forming a virtuous ecological system.
"By employing such methods, we can not only gain a deeper understanding of individual cognitive processes but also explore how these processes interact with and influence each other within social environments. This interdisciplinary approach contributes to building a more comprehensive framework for understanding that applies across a broad spectrum from personal thought to group interactions. Therefore, dynamic epistemic logic provides a powerful analytical tool for both theoretical research and practical applications."[15]

5. HOW DOES LOGICAL DYNAMICS FACILITATE INTERDISCIPLINARY EDUCATION AND RESEARCH?

Logical dynamics is oriented towards cognitive research, and therefore, we primarily support interdisciplinary education and research from the perspective of thinking, which involves knowledge generation and cognitive processes. This encompasses three dimensions: activating the interdisciplinary nature of research and education based on the philosophical perspectives in logical dynamics; enhancing interdisciplinary participants' understanding of thinking abilities through the representation of cognitive processes by dynamic epistemic logic; and integrating the analytical representation of cognitive thinking abilities into the teaching applications of interdisciplinary education.

Perspective Transformation:
Activating the Interdisciplinary Nature in Research and Education

Logical dynamics also represents a philosophical perspective, as Van Benthem has pointed out, there is a shift from the focus on static concepts and rules within logic to a parallel investigation of the logical structure of actions and processes that create and alter these concepts and attitudes [15] . Here, emphasis is placed on the transformation of perspective from static to dynamic, which serves precisely as the catalyst for further activating the interdisciplinary nature in research and education.

Transferring this understanding to the realms of research and education, we can interpret it as follows: although both research and education are inherently dynamic processes, in today's era, the isolated development of research and education within single disciplines can be considered a form of "stagnation." To uphold the mission of education and research—as spiritual activities pursuing knowledge, understanding, and truth—it is necessary to undergo a transformation of perspective. This involves focusing on dynamic processes that transcend multiple disciplinary boundaries and continuously seeking ways to strengthen connections between disciplines. Such an integrated perspective will provide an inexhaustible driving force for the continuous development of interdisciplinary research and education. Education and research are directly or indirectly interconnected through cybernetic relationships, and the activation of interdisciplinary nature further promotes positive interaction and common development between education and research.

Cognitive Representation:
Enhancing the Understanding of Thinking Abilities among Interdisciplinary Participants

Logical dynamics provides a theoretical analysis and formal tool for addressing the cognitive challenges faced in interdisciplinary communication and cooperation, directly tackling the most central issues within these challenges: how to understand and consciously apply interdisciplinary thinking skills? Dynamic

epistemic logic can clearly dissect and construct cognitive processes, identifying and representing higher-order cognitive skills such as critical thinking and reflective thinking. It focuses on core elements involved in high-level cognition, like contemplating "what I know that I know" (metacognition) and inferring "what I know that he knows" (theory of mind) .

Clear cognitive representations enable individuals to more deeply comprehend their own cognitive processes and the mental states of others, grasping and enhancing interdisciplinary thinking abilities from a more fundamental source. These abilities allow researchers to transcend localized thinking patterns, understand the perspectives of collaborators, and engage in reflective, innovative, and collaborative problem-solving.

Metacognition, which is defined as "an individual's cognition about their own learning and cognitive processes," can be represented in dynamic epistemic logic concerning self-reflective abilities as $\mathrm{K}_1\varphi \rightarrow K_1(\mathrm{K}_1\varphi)$, a logical formulation that expresses metacognitive awareness[16].

Here, φ represents a specific proposition or piece of information. The operator K denotes the knowledge operator for a given agent, with subscripts on the K operator distinguishing between different agents. For instance:

$\mathrm{K}_1\varphi$ means "Agent 1 knows φ."

$\mathrm{K}_1(\mathrm{K}_1\varphi)$ means "Agent 1 knows that he/she know φ."

The arrow ($\rightarrow$) signifies that if Agent 1 knows something ($\mathrm{K}_1\varphi$), then they are also aware of possessing this knowledge ($\mathrm{K}_1(\mathrm{K}_1\varphi)$). This represents reflection—a critical component of metacognitive skills. In essence, when an individual recognizes not just the content of their knowledge but also the fact that they possess such knowledge, it demonstrates a level of introspection and self-awareness essential to metacognition. This logical construct provides a formal method to analyze and understand how individuals perceive and regulate their own cognitive activities, thereby enhancing our comprehension of learning processes and cognitive strategies.

Theory of Mind, which refers to "an individual's ability to understand the mental states of others, such as beliefs, desires, and intentions," can be represented through dynamic epistemic logic as $K_1(K_2\varphi)$, reflecting the agent's recursive understanding of another's mental state.

Here, $\mathrm{K}_1(\mathrm{K}_2\varphi)$ means "Agent 1 knows that Agent 2 knows φ." Expanding further, if we wish to express deeper levels of cognitive nesting, such as "I know that he knows that I know something," it can be written as: $\mathrm{K}_1\big(\mathrm{K}_2(\mathrm{K}_1\varphi)\big)$. This represents a higher-order Theory of Mind capability, where one not only understands what others know but also comprehends the awareness others have of one's own knowledge. Such representations in dynamic epistemic logic provide a formal framework for analyzing and understanding the complex recursive processes involved in human social cognition. They allow researchers to model and study how individuals perceive and interpret the mental states of others, which is crucial for effective social interaction and cooperation.

The above is merely the most basic formal representation of thought based on dynamic epistemic logic. In specific cognitive practices and complex scenarios, dynamic epistemic logic can not only cover a broader range of information processing but also deeply represent cognitive interactions and belief revisions among multiple agents. For instance, in a social network or collaborative environment involving multiple participants, each agent may hold different initial beliefs, which will undergo a series of complex adjustments and reconstructions as new information continues to flow in.

Instructional Application:
Integrating Cognitive Representation Comprehension into Interdisciplinary Teaching Design

As Brand and Triplett have noted, "Interdisciplinary teaching is not just an organizational strategy; it is also a way of thinking about the purposes of schooling, the sources of the curriculum, and the use of knowledge" [17]. At the same time, interdisciplinary teaching aims to help students develop a "methodological foundation" and "cognitive flexibility," encouraging them to continuously explore alternative ways of cognition [5][10]. Furthermore, it assists students in building the thinking skills necessary for engaging with complexity, thereby equipping them to deal with uncertainty.

From the aforementioned cognitive representations, it can be seen that logical dynamics and dynamic epistemic logic emphasize intelligent interactions among multiple agents. This dynamic perspective is beneficial for teaching and aligns well with the design objectives of interdisciplinary education. From both internal and external high-order cognition perspectives, metacognitive abilities can assist researchers in transcending local thinking and considering problems from a global viewpoint; theory of mind capabilities, on the other hand, help researchers better understand their collaborators' viewpoints. The dual-driven high-order cognitive representation of these two aspects can be integrated into the curriculum design of interdisciplinary education (such as sharing and evaluation stages). Such interdisciplinary educational courses will prompt students to reflect on what they already know and, more importantly, how they acquired this knowledge. Meanwhile, students can gain deeper insights into others' thought processes and learn to understand and analyze things from different angles [18].

Moreover, these modes of thinking strike at the heart of critical thinking, since critical thinking itself is a form of higher-order thinking that encourages skepticism towards one's own and others' thoughts. Therefore, during this process, students come to understand their cognitive abilities more deeply, take the initiative to construct and perfect their cognitive systems

continuously, and enhance their critical thinking, reflective thinking, and innovative capabilities.

6. LOGICAL THINKING FRAMEWORK EMPOWERS INTERDISCIPLINARY COMMUNICATION IN THE ARTIFICIAL INTELLIGENCE ERA

In today's era of artificial intelligence, generative artificial intelligence (such as large model technologies) has been widely integrated into multiple domains including social media platforms, information service systems, and educational systems, profoundly altering people's lifestyles and work patterns. AI not only assists teachers in lesson preparation and the development of highly interactive teaching materials but also helps students acquire personalized learning path planning. Moreover, within academic research, AI has sparked the wave of the "fifth paradigm of scientific research driven by artificial intelligence," indicating that AI has become a crucial tool for interdisciplinary education and research, deeply participating in interdisciplinary development.

So how do we understand AI's thinking (such as chain-of-thought techniques)? How can we collaborate with AI? And how can we engage in inspiring communication with AI? These questions require us to enhance our artificial intelligence literacy, whose foundation lies in logical general education literacy, because "a logical perspective is helpful for asking the right questions, designing inspiring experiments, and precisely defining appropriate levels of capability" [19]. If interdisciplinary teams possess an integrative cognitive logical thinking framework, then collaboration and communication with AI agents will be more efficient and valuable, while also promoting faster innovation and creation.

7. CONCLUSION AND OUTLOOK

Interdisciplinary participants, if lacking in interdisciplinary thinking literacy, will struggle to find conceptual commonalities during communication, causing projects aimed at "integrative interdisciplinarity" to degenerate into "additive multidisciplinary" projects. This is one of the greatest cognitive challenges faced by interdisciplinary research and education. This paper elaborates from three dimensions on how logical dynamics can address interdisciplinary cognitive challenges:
Firstly, perspective transformation: activating the interdisciplinary nature inherent in "research" and "education". Secondly, cognitive representation: enhancing interdisciplinary participants' understanding of cognitive abilities. Thirdly, integrating cognitive representation comprehension into interdisciplinary teaching design. At the same time, this article emphasizes that logical thinking can significantly facilitate interdisciplinary communication in the era of artificial intelligence.

"Integrating Logical Dynamics to Enhance Interdisciplinary Thinking Skills" represents a structured approach to thinking, as it provides a dynamic theory and a set of analytical tools that guide individuals on how to analyze information more effectively, solve problems, and foster innovation and development. At the same time, it reveals that the interaction between different disciplines is characterized by high complexity, uncertainty, and conceptual ambiguity. Therefore, one must continuously seek paths towards "dynamic unity from diversity" through an adaptive and evolving approach. This comprehensive perspective is particularly crucial for nurturing researchers with critical thinking skills. On a deeper level, logic aids people in understanding both the possibilities and limitations of interdisciplinary research and education.

More encouragingly, there exists a positive feedback loop between logical dynamics and interdisciplinary communication, forming a virtuous interaction. Logical dynamics assists interdisciplinary communication in addressing cognitive challenges and offers new approaches to solving complex social problems. Meanwhile, the sound development of interdisciplinary education and research contributes to advancing logical dynamics from mere theoretical and technical studies towards broader practical applications.

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