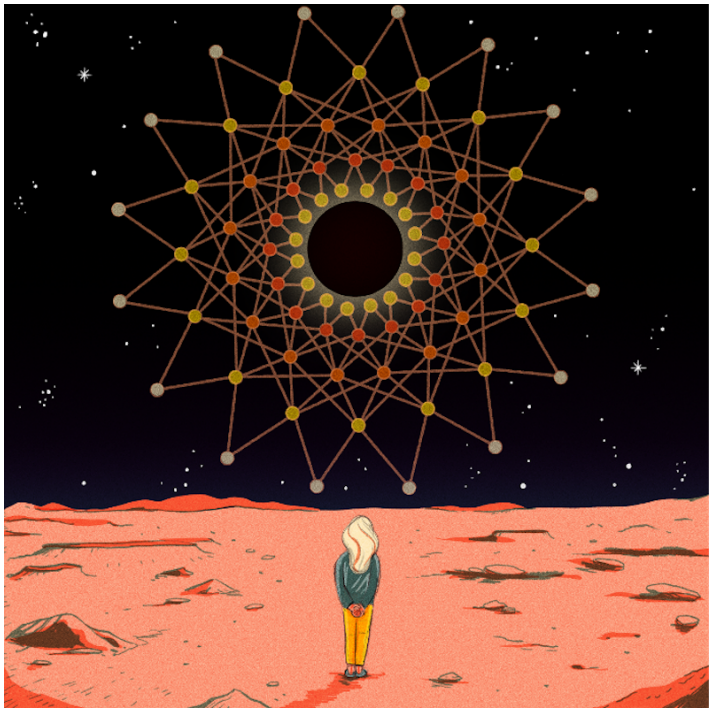
The Art of Asking Questions: From Stephen Hawking to AI

A former collaborator of Stephen Hawking reflects on what his approach to research can teach us about doing science with AI.

By **Marika Taylor**

This article is part of a series that Physics Magazine *is publishing to mark the 50th anniversary of Hawking's formulation of the information-loss paradox.*

Half a century has passed since Stephen Hawking published his seminal papers on black hole thermodynamics [**1**] and the information-loss paradox [**2**]. As a former student of his, I am often asked about what it was like to work with him. Reflecting on my experience, I am struck by the parallels between the way Hawking worked with his collaborators and the way scientists are beginning to work with artificial intelligence (AI). AI is already transforming science, but my time with Hawking reminds me of something fundamental: However powerful our tools may be, scientific progress depends on our ability to ask the right questions.



A black hole surrounded by a web of interconnected nodes evokes emerging links between the structure of spacetime and quantum information, including quantum error correction. The observer represents physicists using thought experiments to explore the mysteries of black holes.
Credit: **Oliver Dean**

The information-loss paradox was born out of thought experiments. What happens to matter and radiation that fall into a black hole? When the black hole evaporates through Hawking radiation, does that radiation preserve the information about what fell in? In his information-loss paper, Hawking argued that information is irretrievably lost. This conclusion would imply a breakdown of predictability and a violation of unitarity, a central tenet of quantum mechanics.

When Hawking wrote these papers, he could not have predicted that the information-loss paradox would still be inspiring new research directions today (see **News Feature: Hawking's Black Hole Paradox Exposed Clash Between Physics Theories**). Nor could he have anticipated the deep connections that would emerge between black holes and quantum information or the paradigm-shifting insights into gravity that his work would inspire. Such insights include the holographic conjecture, which points to a tantalizing link between gravity and quantum physics: Gravity might emerge from quantum physics in a universe with one fewer dimension. The information-loss paradox continued to fascinate Hawking throughout his career. Toward the end of his life, he was still exploring possible

resolutions (see **Viewpoint: Black Holes Have Soft Quantum Hair**).

Early in his career, Hawking was still able to carry out calculations with pen and paper, but as his ALS progressed, he lost the ability to write. He could still do a great deal of calculation in his head, but he increasingly relied on collaborations with graduate students and other colleagues to work out the computational details.

By the time I started working with Hawking in the late 1990s, he was using a speech synthesizer to communicate, laboriously typing out sentences word by word. My fellow graduate students and I helped test his ideas by computing the outcomes of proposed thought experiments. Communication was slow, and he would often give us just a few sentences of guidance about what he wanted to explore. We would then study the literature, conceive other thought experiments, and compute and interpret their outcomes before returning to him to discuss.

Sometimes, he would get frustrated because we had misinterpreted his guidance or were not exploring the directions he had expected. At other times, he would be pleasantly surprised when an approach proved richer than anticipated or a collaborator found an unexpected solution to a problem. With years of experience doing calculations in his head, Hawking was extremely good at finding errors in the work done by others. By the time I was a graduate student, theorists in our field were using both pen-and-paper calculations and computer programs. Hawking could spot inconsistencies and mistakes even in complex, computer-assisted calculations.

I remember one occasion when Hawking and I were working on rotating black holes in the presence of a cosmological constant, a quantity that can account for the accelerated expansion of the Universe. He asked me to look for new solutions to Einstein's equations describing such black holes. These equations are notoriously difficult to solve, and I doubt he expected me to succeed. But I came back with exact solutions in various spacetime dimensions, to which he responded with a huge grin. After studying them carefully, he typed just three words: "Rotation versus Lambda." He had spotted a deep link between black hole rotation and the cosmological constant, leaving me to work out the details. That episode captures his extraordinary ability to set research on a new course with a few well-chosen words.

Recently, I have often found myself comparing my experience with Hawking to that of using large language models (LLMs). Just as Hawking had to carefully formulate his guidance to us, one needs to think carefully about crafting effective prompts for LLMs. Like collaborators responding to Hawking's input, LLMs can search the literature, assimilate information, and apply it to the question posed. They may go off in unexpected directions, some useful and others less so. And because LLMs make errors, their results need to be checked for consistency and accuracy, much as Hawking scrutinized the calculations that his collaborators presented to him.

When I use LLMs in my own research, I often imagine what prompts Hawking would have given to elicit the best responses. Communication was so slow for him that he had to make every word count. He would reflect deeply as he selected words through his synthesizer. Sometimes, he would pause in the middle of typing a sentence, erase it, and start again, having found a phrasing that conveyed his ideas more effectively. Seeing Hawking at work taught me the art of asking the right questions, a lesson that I find increasingly valuable as I explore the possibilities of LLMs and that I hope to pass on to my own students.

We cannot know for sure what Hawking would have thought of LLMs, but I believe he would have been excited about their potential to accelerate scientific discovery. I can picture him prompting LLMs much like he prompted his collaborators.

In my own research, I have found LLMs particularly helpful in uncovering hidden patterns and connections in data and literature, as well as in exploring a much broader range of possibilities than previously feasible. I am currently working with a mathematician on a conjectured duality between gravity and quantum theory. Exploring this conjecture requires bringing together results from different areas of mathematics, some seemingly unrelated to our problem and dating back several decades. LLMs have been invaluable in identifying relevant results—now it's up to us to study the papers in detail. In another project, a student and I are developing conjectures about certain types of scattering amplitudes that have received relatively little attention. Here, LLMs have helped us develop such conjectures by working through many examples, with us

carefully checking each step of the calculations.

What I envision as truly transformative is the use of AI to uncover previously unknown connections between different areas of mathematics and physics. Fifty years ago, Hawking could not have anticipated the deep links between gravity and quantum theories of particle physics that we recognize today. Could AI help us discover similarly unexpected relationships, opening entirely new directions for theoretical physics?

Today, much of the scientific community thinks that information can indeed be recovered from black holes. But fundamental questions remain about how this happens, questions that touch on the quantum nature of gravity. Perhaps AI assistance will prove crucial in finding a complete resolution of the information-loss paradox.

In a sense, AI puts researchers in a position similar to Hawking's. Just as he relied on collaborators to carry out calculations beyond his capabilities, we can now draw on computational and analytical resources far beyond those we could access until recently. But however powerful these tools become, our ability to ask the right questions, draw on our human intuition, and guide investigation will remain central to scientific progress.

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REFERENCES

1. S. W. Hawking, "Black holes and thermodynamics," **Phys. Rev. D 13, 191 (1976).**
2. S. W. Hawking, "Breakdown of predictability in gravitational collapse," **Phys. Rev. D 14, 2460 (1976).**