AI is transforming how science is done. Science education must reflect this change.

Sibel Erduran

There is growing interest in the use of artificial intelligence (AI) in science education. Many issues and questions raised about the role of AI in science education target primarily science learning objectives. They relate to AI's capacity to generate the tools for teaching, learning and assessment, and the advantages and disadvantages of using such tools. But another important discussion receiving far too little attention in science education concerns how AI is transforming the nature of science (NOS) itself and what such transformation implies for the education of young children. For education it is critical to ask what AI-informed NOS is, what skills it demands of learners, and how schools can aim to achieve them.

With respect to advantages of AI for teaching, learning, and assessment, the use of simulations including immersive learning experiences has been advocated as an important benefit. Similarly, educators have observed that AI presents a powerful means to personalise education by tailoring content and experiences in ways that may not have previously been possible. For example, a student's engagement with a task may be monitored closely and appropriate feedback provided in a specific manner where feedback is most needed. In relation to potential disadvantages, questions such as the following have been raised: What becomes of learning when a student can easily compose text for homework using AI tools? How can students' understanding be measured in a way that ensures the measurement is about the learning and not about a residual of technology?

Some of the concerns about the impact of AI on learning assume outdated notions of human learning. Traditional science education has promoted transmission of facts and recall of information as indicators of learning. For example, traditionally students may have been expected to memorize the chemical equation of photosynthesis or be able to recite Ohm's law. In this depiction of learning, information would be easily retrieved through AI, rendering ambiguity in students' learning outcomes. In contrast, more contemporary perspectives on learning advocate skills such as critical thinking as important outcomes of learning which can potentially be copied to an extent but difficult to mimic through AI. Future-oriented skills such as scenario thinking, systems thinking, and managing uncertainty and complexity require more than recall or even management of big data sets. They imply considerable creativity and innovation. Some cognitive psychologists are arguing that although AI can help to summarise and generalise existing information, it is not designed to fulfil more sophisticated human skills such as theory formation that require innovation. However, emerging research and development in AI is challenging such views, for example by exploring potential for AI systems to highlight blind spots in scientific hypotheses and to help generate new questions.

In terms of science education and NOS, there is evidence that stakeholders engaged in producing educational policy acknowledge the importance of NOS and draw on research findings about effective teaching and learning of NOS. However, further articulation is needed to unpack the relationship between AI and NOS for educational research and practice as well as policy. Contemporary reflections on NOS in science education research have yet to address AI and its implications for how the scientific endeavour is changing. The conventional gap between professional science and school science can be wide but it now seems to be increasing even at a faster pace.

AI is already influencing how science is done. Scientists are using AI to generate hypotheses, design experiments, collect and interpret data and gain insights that might not have been possible using traditional scientific methods alone. In terms of the reasoning and knowing aspects, scientists often construct models from data to explain and predict phenomena. With the advance of AI, data sets can help scientists make sense of an enormous amount of information. But AI systems can also report misleading information if the data on which the systems are trained and operating are not reliable or are biased. The abundance and quality of data sets are known to be biased, often unintentionally. In health data, for instance, AI-based dermatology algorithms have been shown to diagnose skin lesions and rashes less accurately in Black people than in white people, because the models are trained on data predominantly collected from white populations.

Professional bodies are making recommendations for responsible use of AI in scientific research. These raise issues of transparency, risk, and participatory methods that are worthy of note for how AI-informed science ought to develop. Transparency calls for clear documentation of participants, data sets, models, biases and uncertainties. Risk implies the management of risks and biases in data sets and algorithms and how they might affect the outcomes including unintended consequences. Participatory methods call for ensuring that research designs are inclusive and engage researchers with communities at risk and include domain expertise. These issues are implying how NOS needs to accommodate cultural norms, such as transparency of data and processes; evaluation criteria for scientific knowledge such as evaluation of biases; social values such as managing consequences of risks; and inclusive methodologies to incorporate not only expertise but also appropriation of community knowledge.

In light of the emerging trends in how AI is used in scientific research, the question arises as to how school science can help prepare future scientists to understand NOS in the age of AI. Two questions thus emerge for science education: (a) What does AI-informed NOS mean for school science? (b) What should be prioritised as aspects of AI-informed NOS at the secondary education level? Some might argue that the use of AI in basic science research is far too sophisticated to be relevant for the purposes of secondary schooling. Others might claim that young children are not cognitively capable of understanding such advanced means of conducting science research. Such potential positions are open to empirical investigation where school-based research projects can test the developmental capacity of students and the impact of AI-based interventions on students' learning of NOS.

Some example aspects of AI in scientific research (e.g., scientific methods, cultural context, professional recommendations) already have substantial implications for school science. Although science curricula around the world include some of the traditional aspects of scientific inquiry such as experimentation, and data collection and interpretation, other relevant aspects such as modelling, while advocated for many years in the science education research community, are still underrepresented in curricula. Similarly, while in some educational systems, the themes of objectivity and accuracy of data may be set as learning outcomes, these aspects of science are virtually inexistent in a way related to the advancements in AI and its potential contribution to propagating biases. Drawing out some educational adaptations of professional guidelines will help educate future scientists in instilling in them understanding and responsibility about the ethics of AI in scientific research.

The impact of AI on NOS is a tall order for science education. It calls for a systemic approach to reform across the entire sector. There are implications for restructuring the science curriculum, teaching and learning, and teacher education, to name a few aspects. As a matter of priority, the science curriculum content will need to capture nuances about AI-informed NOS including the developments about how AI is influencing scientific methods and hypotheses. Other aspects such as models and modelling of large data sets in the context of AI will also be integrated into secondary education along with themes such as bias in data and risks involved in errors. Such aspects relate to what are currently being referred to as the scientific practices in some curriculum standards, which can act as the specific locus for revision. New teaching and learning tools and strategies will need to be designed and tested to identify effective ways of capturing in the classroom the changing face of science. Many secondary teachers and students are already using platforms such as ChatGPT. In fact, the use of ChatGPT can potentially simulate what scientists themselves are doing as they use such tools for generating literature background for academic manuscripts. Pedagogical strategies such as questioning (e.g., "*How do we know that this text produced by ChatGPT is accurate?*") can be considered for specific purposes of AI-infused NOS learning, for example, to encourage students to generate and apply evaluation criteria for accuracy. Such approaches, however, will need to be accompanied by training of teachers not only to use AI tools and data, but also to understand how science is changing more broadly in the AI age.

Although the AI-infused NOS agenda in science education is a tall order, some existing educational interventions can provide some guidelines for aligning its objectives within the education ecosystem and highlighting how to tackle conventional blind spots in educational reform. For example open schooling networks can be established to foster learning communities involving a range of stakeholders including students, teachers, teacher educators, scientists, and policymakers. If secondary science education is to raise the future generation of scientists and equip them with timely and relevant skills, then it is essential that secondary science education comes on board with the latest developments in AI-informed scientific research. Otherwise, the gap between professional science and school science is likely to grow at such a rate that by the time secondary students enter university, their understanding of NOS will already be outdated.