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The impact of artificial intelligence on scientific practices: an emergent area of research for science education

Sibel Erduran [a] and Olivia Levrini [b]

[a]Department of Education, University of Oxford, Oxford, UK; [b]Department of Physics and Astronomy, University of Bologna, Bologna, Italy

ABSTRACT
Artificial intelligence (AI) is now a major driver of societal acceleration making a significant impact on science and science education. AI is used by scientists to generate hypotheses, design experiments, collect and interpret data in ways that were not previously possible with traditional methods alone. Science education research is increasingly paying attention to the role of AI in teaching and learning. However, a significant gap in the emerging science education literature on AI concerns the impact of AI on scientific practices themselves, and implications such impact for science education. The article uses the NRC (2012. *A framework for K-12 science education: practices, crosscutting concepts, and core ideas*. National Academies Press.) framework of 'scientific practices' to trace example uses of AI in scientific practices and raises questions for science education. The questions relate to the relevance of AI-informed scientific practices for science curriculum, teaching and teacher education at the secondary level. The ultimate purpose of the article is to highlight that the sooner the role of AI on scientific practices are researched and applied in science education policy and practice, the less likely that education will become outdated in helping students thrive in the fast changing landscape of scientific research.

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1. Introduction

Artificial intelligence (AI) is now a major driver of societal acceleration (Gruetzemacher & Whittlestone, 2022), making a significant impact on science (e.g. AAAS, 2021) and science education (e.g. Alasadi & Baiz, 2023; Cooper, 2023) raising questions, for example about the use of AI tools in teaching (Talanquer, 2023) and assessment (Clark, 2023). Increasingly, there is a blurring of distinction between human, machine and nature, as well as a shift from information scarcity to information abundance (Floridi, 2015). AI is currently used by scientists to generate hypotheses, design experiments, collect and interpret data in ways that were not previously possible with traditional methods alone (e.g. Wang et al., 2023).

CONTACT Sibel Erduran Sibel.Erduran@education.ox.ac.uk Department of Education, University of Oxford, 15 Norham Gardens, Oxford OX2 6PY, UK

Not surprisingly, science education research is increasingly paying attention to the role of AI in teaching and learning (e.g. Mishra et al., 2023). In a recent systematic review of research, Jia et al. (2023) examined the trends and research foci of AI by using a bibliometric and content analysis to examine the characteristics of 76 studies on AI in science education indexed in *Web of Science* and *Scopus* from 2013 to 2023. The results indicate that AI-based science education has experienced increasing influence over the past decade. The findings indicated that the foci of research were themes such as educational robots, data mining and machine learning as incorporated into primary and secondary science education. The AI applications were primarily about educational robots, machine learning, data mining, intelligent tutoring systems, automation and detection/prediction applied to science content. Another recent systematic review taking a broader view on machine learning in education highlighted some areas of future research including how machine learning can be integrated into subject domains other than computing as well as the need for more evidence of societal and ethical implications of machine learning (Sanusi et al., 2023).

A significant gap in the emerging science education literature on AI concerns the impact of AI on scientific practices themselves, and what implications such impact has for science education. Consider, for example AlphaFold, an AI tool named in 2021 by *Nature Methods* the 'Method of the Year 2021' (2022). The tool has enabled scientists to predict protein-folding with great accuracy, already considered to have initiated a revolution in biology (Ewen, 2022). The use of AI is raising some fundamental questions about scientific practices, particularly in relation to *how* science is carried out and *who* indeed does science. 'Scientific practices' have been a central theme of recent educational reforms in science education in the United States (e.g. NRC, 2012) and the interest in this theme has also extended to the rest of the world (e.g. Costa & Broietti, 2021). The focus on scientific practices has been a major concern to science educators given the 'practice turn' more broadly in science studies (Berland et al., 2016) which highlighted the importance of students' engagement in how scientists *do* science. *Next Generation Science Standards* (*NGSS*) (NGSS Lead States, 2013) in the USA were guided by the recommendations of NRC (2012) which defined science and engineering practices as follows:

- Asking questions (for science) and defining problems (for engineering)
- Developing and using models
- Planning and carrying out investigations
- Analysing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations (for science) and designing solutions (for engineering)
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information.

Such characterisation of scientific practices has been used explicitly for curriculum analysis internationally, for example by Nguyen et al. (2023) who examined the national science curricula of Taiwan and Vietnam. Although in different national contexts, the processes outlined by NRC (2012) and subsequently by NGSS (NGSS Lead States, 2013) may not be explicitly defined as 'scientific practices', they nevertheless relate to aspects of science such as investigations, argumentation and explanations that feature in science curricula from many countries in Europe (Mork et al., 2022), South East Asia (Choi et al., 2021) and Africa (e.g. Ramranain, 2020). Hence, the characterisation of scientific practices as described by NRC (2012) and NGSS (NGSS Lead States, 2013) can be a useful heuristic to guide discussions on scientific practices for educational purposes.

In this article, we consider example uses of AI in scientific practices based on research published in physical and natural sciences journals. Our aim in doing so is to illustrate the relevance of AI for contemporary scientific practices and thus for science education. By using the NRC's (2012) framework as a heuristic to trace example scientific practices currently employing AI tools, we explore how new frontiers of scientific research are opening up for science education researchers to consider. We raise some research questions for science education as a means to invite the readership and authorship of the *International Journal of Science Education* to explore a potential new research territory. The sample questions relate to the relevance of AI-informed scientific practices for science curriculum, teaching and teacher education at the secondary level. The ultimate purpose of the article is to ensure that students who are potentially future scientists and scientifically literate citizens are able to decipher how AI is impacting the nature of science (Erduran, 2023).

2. Impact of AI on scientific practices

The impact of AI on scientific practices is vast and changing fast. There are now plenty of examples related to biology, mathematics, physics and chemistry reported in professional journals as exemplified in this section. The framework of scientific practices from NRC (2012) italicised in subsequent text is used to highlight some areas of research that are relevant for secondary science education. A review article published in *Nature* (Wang et al., 2023) explores the ways in which AI is now helping scientists in 'asking new questions' and generating new hypotheses in particle physics, materials science, biology, chemistry and other fields leading to the 'planning and carrying out investigations'. Indeed, AI is now enabling scientists to generate new hypotheses (Hutson, 2023) and design investigations that would not have been possible with traditional scientific methods alone (Wang et al., 2023). The emerging literature on the use of AI in scientific practices include 'developing and using models' in biology. Consider the molecular dynamics simulations of SARS-CoV-2, the virus responsible for the global pandemic of the past few years. Using AI tools, Casalino et al. (2020) uncovered new biological functions of the spike protein that show different behaviours in the open and closed conformations. This discovery led to a change in the view of glycans in biological systems and inspired new ways to analyse them, contributing to how scientists engage in 'analysing and interpreting data'.

A relevant example for 'using mathematics and computational thinking' is about the case of anomalies in data. AI is now helping scientists estimate the confidence of predictions to directly search for anomalies in data (Nigam et al., 2021). AI's ability to uncover hidden regularities was demonstrated in mathematics, in which an AI hinted at relations between previously unconnected invariants in knot theory and allowed mathematicians to conjecture and prove a new theorem (Davies et al., 2021). One recent, concrete example in astronomy is the rediscovery of Newton's law of gravitation from realworld observational data of planets and moons in our Solar System from the last 30 years (Lemos et al., 2022). High-quality predictions have been made using AI about the equations of motion as well as accurate predictions of the planet masses. The tool is enabling the 'construction of explanations' and predictions as well as 'engaging in argument from evidence'. Several other advanced computational techniques have been developed to interrogate scientific literature and investigate it systematically (Olivetti et al., 2020). Such investigations are helping scientists derive complex scientific ideas, such as the relations between different crystal structures (Schwalbe-Koda et al., 2019), highlighting the practices of 'obtaining, evaluating and communicating information'.

In some cases, the use of AI in science is illustrating how the nature of scientific practices is shifting in terms of new possibilities in conducting research, such as the generation of hypotheses through analysis of vast amount of data that would not have been possible otherwise. Questions are also being raised about the ethical use of AI, as some data sets used in machine learning are known to be biased, prompting professional bodies to generate guidelines for responsible use of AI (Stall et al., 2023). Although scientists are engaged in generic types of practices that are foundational to science (e.g. hypothesis generation, planning investigations), the nuance of how these practices are shifting with the advance of AI use are worth considering in science education, particularly if science education aims to prepare students for a fast changing landscape of scientific research.

3. Emerging questions for science education research

While exploring the implications for science education of the use of AI in scientific practices, it is worthwhile to consider the broader societal context that is creating demands on citizens and scientists alike. The developments in AI are now so fast that we are living in what the sociologist Hartmurt Rosa calls 'the society of acceleration' (Rosa, 2013). Within the society of acceleration, educational systems often remain static, rigid and do not appear able to keep the pace of change (OECD, 2019). As a result, a serious gap of knowledge and skills emerges from what the traditional educational organisations are producing and what the society requires. Another worrying phenomenon is 'future shock' (Toffler, 1970), a certain psychological state that individuals and entire societies experience when they perceive 'too much change in too short a period of time'. Because of the exponential speed of change, people have a hard time catching up the sense of change and, feeling scared, they don't want to know about the science behind technological developments.

One aspect of alienation with respect to AI is understanding of the language through which a machine is programmed. In the context of science education, if students have not been exposed to any computer science, then it is likely that they will feel such alienation in relation to how AI is involved in science. In terms of understanding language of programming, some machine learning and teaching initiatives maintain the traditional (i.e. textual or block-based) approach, using traditional programming to teach machine learning topics while other initiatives change the focus from programming to the design of the neural network structures (Vartiainen et al., 2021). These different orientations inevitably can lead to confusion from students' point of view about the role of programming in AI. Another educational approach is to ask students to train machine learning models with data, the curation, cleaning and labelling of data (Sanusi et al., 2023). While such aspects of learning AI (i.e. understanding how AI works) are important and need to be researched further to address different learning outcomes for science education, our primary objective in this article is to focus on an underspecified aspect in the existing literature on AI in science education (e.g. Alasadi & Baiz, 2023), namely the impact of AI on scientific practices themselves. We are raising questions not about the mastery of technical skills (although we also consider them to be important, particularly in dealing with alienation about programming) but rather about the understanding of how AI more broadly is infiltrating how science is done. Considering the fast pace of innovation in AI, science education will benefit from research that can help provide insight into how the education of secondary students can be aligned with contemporary scientific practices influenced by AI.. A key question arising from our discussion is why AI-informed scientific practices need to be integrated into science education in the first place. The basic assumption underpinning this question is that professional and school science practices need to be aligned if they are to ensure that students are well equipped with scientific literacy (e.g. Phillips & Norris, 2009).

It is thus timely to carry out research about (a) different aspects of scientific practices, for example the nature of modelling in science facilitated by AI, (b) students' learning of the role of AI in advancing scientific practices, for example how decision-making with evidence is influenced when evidence is derived from AI, and (c) teachers' training to support them in dealing with how AI is influencing scientific practices, for example in understanding and teaching the role of bias in AI tools. Such research themes are related to concerns about the curriculum, teaching and learning, and teacher education where questions can be raised as follows:

- What is relevant content from AI-informed scientific practices that can be integrated into secondary school science curricula? What cognitive demand do such practices place on the learners and how can the science curriculum be structured for effective progression of scientific practices across secondary schooling?
- How can the teaching and learning of science be enhanced by the inclusion of recent developments on AI-informed scientific practices? What is the impact of integration of AI-informed scientific practices on students' understanding of and engagement in science?
- What pedagogical tools and strategies are effective in supporting the learning AI's role in scientific practices? How can AI tools be adapted for teaching and learning of scientific practices at the secondary level?
- How can teacher preparation programmes support teachers in catching up with fast changing developments in AI and science? How can university science departments as well as science teacher education programmes adjust their provision to integrate AI?

The advancements in AI raise questions not only about what now characterises scientific practices but also about agency in scientific practices. In other words, *who* does science can be questioned in terms of which scientific practices are carried out solely by humans and which are mediated by machines. As AI tools increasingly become an integral part of scientific practices, the element of agency has implications for science education given learning environments will need to adapt to AI as a 'collaborator' in scientific practices, where students and teachers jointly engage with such tools in addressing scientific problems. Clearly, the inclusion of new content such as the role and impact of AI on scientific practices will imply new demands on the education sector. Such demands are no different from any new proposal to update or upgrade the educational objectives and outcomes and may require a re-orientation to the content and structure of the curriculum as well as an array of reforms in assessment, instruction and teacher training. As such, the inclusion of AI in science education is a tall order for science education that requires systemic change (Erduran, 2023). However, the sooner the role of AI in scientific practices is researched and applied in science education policy and practice, the less likely that school education will become outdated in helping students thrive in the society of acceleration.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Sibel Erduran http://orcid.org/0000-0001-5226-0136
Olivia Levrini http://orcid.org/0000-0002-4267-3989

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