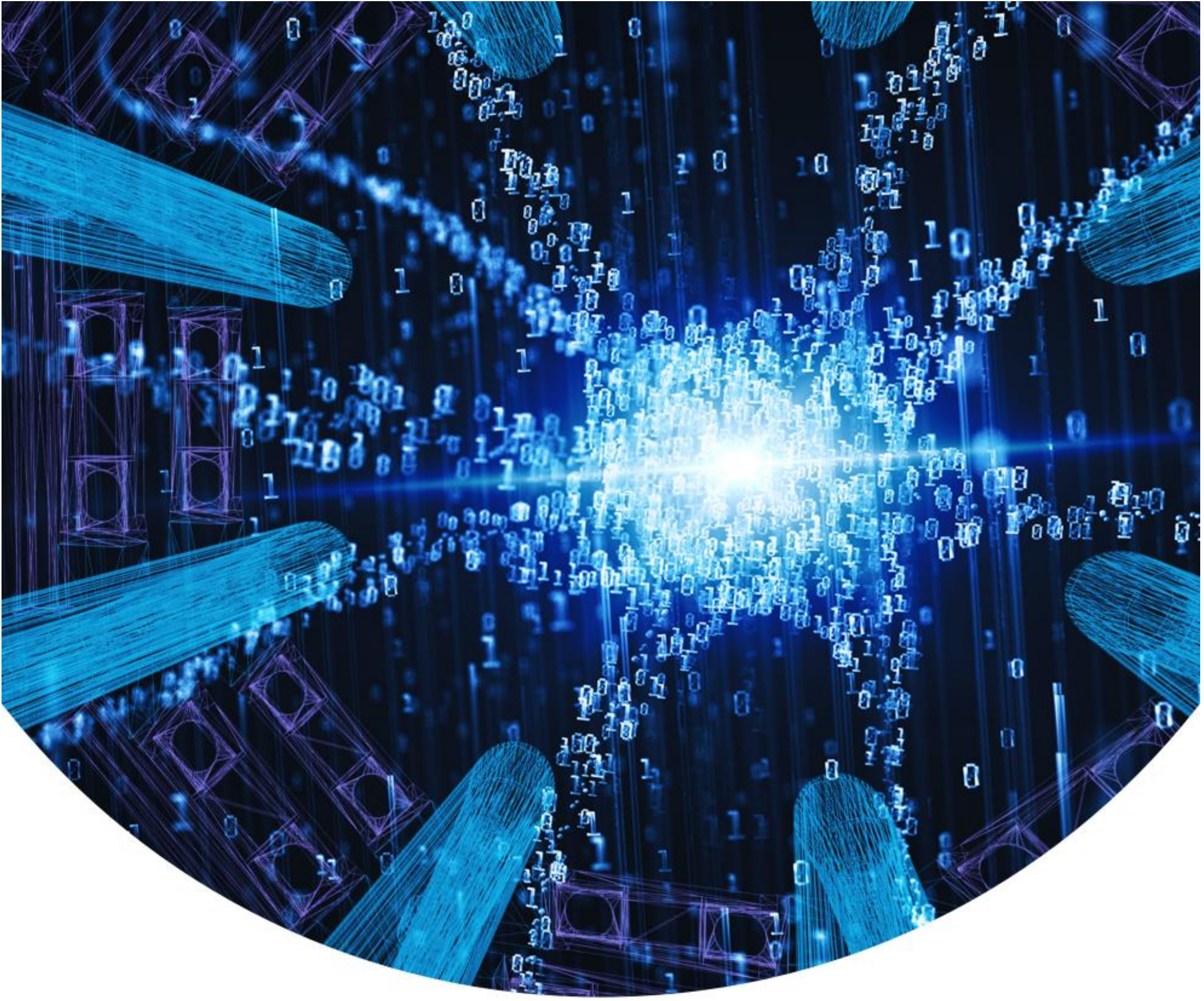

IOP Institute of Physics

Physics and AI

A physics community perspective

iop.org

Image: Photograph: Anthony, Katarina. ATLAS Experiment © 2024 CERN

Contents

Executive summary

Advances in Artificial Intelligence (AI) are taking place faster than ever before, shaping the global economy, and opening potential for new solutions to longstanding societal problems. Governments have responded with national AI strategies, some with a strong focus on AI for science.

Physics has been an early-adopter and is a heavy user of AI, machine learning methods being used in most fields of physics and in all aspects of research. Physics has also been a contributor to AI from the advances celebrated by the 2024 Nobel prize in Physics to the thermodynamics-inspired diffusion models used in generative AI. As both enabler and a beneficiary of AI, it is important to consider the physics perspective in national and international AI strategy – including through a strong focus on the potential of 'AI for Science' [see refs 33-35,39,40,42 in this report].

Based on evidence gathered through a community consultation (a survey with 700 responses and a workshop with experts from academia and industry), this Impact Project Pathfinder investigated the uses of AI in physics, the views physicists hold regarding AI, ways in which AI can boost physics research and innovation and opportunities for physics to contribute to the development of AI – with a view to articulating specific opportunities where IOP could carry out more in-depth work to realise latent opportunities.

AI tools are becoming essential to physics research and the ability to use them well will accelerate future progress. This report identifies some of the needs of the physics community, namely access to AI data and computing infrastructure, skills development and education in AI, career pathways, incentives and frameworks for interdisciplinary and inter-sector collaboration, interdisciplinary research funding, data sharing standards and sustainable software development. Addressing them will help advance scientific discovery in physics and beyond. At the same time, addressing these needs will also maximise the long-standing synergies between physics and AI, as physics research can contribute to important topics in AI such as energy and environmental sustainability, explainability and evaluation, and provide large, well-curated datasets. Furthermore, there are opportunities for academia-industry collaborations in AI to extend the impact of physics research to other sectors in UK and Ireland.

The IOP is a natural forum to foster inter-disciplinary and inter-sector dialogue and collaboration and there is scope for the IOP to identify and progress specific opportunities for AI to advance physics research and for physics to contribute to advances in AI, both enabling technological and economic growth across multiple sectors.

This report provides a first snapshot of the AI landscape from the UK and Irish physics community perspective and baselines the physics community views on issues and opportunities. It does this to identify potential starting points for further IOP led work that can unlock more opportunity from bringing AI and physics closer together. It has been broad-based with more than 700 individuals feeding in – but we are also keen to know if on reading this you think we have missed opportunities or evidence. If you would like to provide any additional views or evidence – please contact us scienceandinnovation@iop.org Based on the evidence gathered though the community consultation and summarised here, the IOP will decide how to take these findings forward.

Key findings

- There is overwhelming consensus that AI has benefits for physics, in particular in data analysis, simulation and task automation (97% of the survey respondents think that AI has some benefits). At the same time, it is widely recognized that AI poses risks mainly inaccuracy, misuse and limited reproducibility (90% of the survey respondents think that AI poses some risks)
- There is a good level of familiarity with AI (66% of respondents have used AI at some point and for 16% of respondents AI is central to their current role and for 44% AI is peripheral to their current role)
- The views of the physics community broadly align with those of the general scientific community, but there are a few discipline-specific differences. There was little concern about the dominance of big tech or about a brain-drain from academia to industry. There was less concern about equity and more about the environmental impact of AI. There was no concern about loss of creativity, but quite a bit of concern about the loss of understanding.
- The community reported a need for skills development and education on AI for physics, highlighted by both survey and workshop.
- The community expressed interest in industry-academia collaborations, highlighted by both survey and workshop.
- Other enablers identified in the survey and workshop are:
    - Interdisciplinary research funding and incentives to enhance interdisciplinary collaborations
    - Access to computational resources/infrastructure and the development of a code of best practice which could include standards for data sharing (and appropriate data infrastructure)
    - Guidance for sustainable software development and sharing (good quality, reproducible software that is well programmable, reusable and findable).
- The following starting points for future work were identified:

- How can physics inform national and international AI strategies, and how can physics better articulate opportunities to accelerate physics discovery and innovation through use of AI as part of 'AI for Science' approaches?
- How can physics address the energy and environmental sustainability issues related to AI?
- How can physics support the development of evaluation methodologies and explainability for AI?
- Physics research is both data- and computing-intensive. How can it benefit from the national AI infrastructure?
- There is need for physicists to develop more AI user skills; equally it is important to better understand the substantial contribution physics skills make to the AI pipeline: what is the relationship between the UK strategy for growing AI and physics skills and talent?

Background

Artificial Intelligence (AI) is a research field established in the 1950s, but over the past decade its technological applications have come to prominence and public awareness. The field made big leaps in 2012 with the introduction of deep learning and in 2017 with the transformer architecture. The application of AI methods to scientific discovery[1,2], or AI for science, have come into the spotlight in the past 5 years, in particular after the breakthrough in solving protein folding[3]. However, physicists were already using AI methods in particle physics as early as the 1990s[4,5], the first applications of machine learning to molecular dynamics simulations emerged before 2010[6] and traditional machine learning methods accelerated landmark results such as the discovery of the Higgs boson in 2012[7].

What is AI?

For the purpose of this report, we take a broad definition of Artificial Intelligence (AI) as a set of technologies enabling computers to perform tasks traditionally associated with human intelligence such as learning, reasoning, analysis, decision making and content generation. We include a wide range of technologies from traditional machine learning (such as logistic regression, random forest, support vector machines, etc), symbolic AI, Bayesian networks, evolutionary algorithms, deep learning, reinforcement learning and generative AI, including large language models.

Physics plays a special role in AI

Physics has inspired a range of advances in AI[8] from the Ising model of a neural network and Boltzmann machines, recognized by the 2024 Nobel prize in Physics awarded to John J. Hopfield and Geoffrey E. Hinton, to geometric deep learning, energy-

[1] Choudhary, A., Fox, G. and Hey, T. Artificial Intelligence for Science: A Deep Learning Revolution, World Scientific (2023) https://doi.org/10.1142/13123
[2] Wang, H., Fu, T., Du, Y. *et al.* Scientific discovery in the age of artificial intelligence. *Nature* **620**, 47–60 (2023) https://www.nature.com/articles/s41586-023-06221-2
[3] *Nature* **588**, 203-204 (2020) https://www.nature.com/articles/d41586-020-03348-4
[4] 1st International Workshop on Software Engineering, Artificial Intelligence and Expert Systems in High-energy and Nuclear Physics (1990) https://cds.cern.ch/record/117039
[5] Denby, B. Neural networks and cellular automata in experimental high energy physics, *Computer Physics Communications* **49**, 429-448 (1988) https://doi.org/10.1016/0010-4655(88)90004-5
[6] Noé, F. et al Machine Learning for Molecular Simulation, Annual Review of Physical Chemistry **71**, 361-390 (2020) https://doi.org/10.1146/annurev-physchem-042018-052331
[7] Radovic, A., Williams, M., Rousseau, D. *et al.* Machine learning at the energy and intensity frontiers of particle physics. *Nature* **560**, 41–48 (2018. https://doi.org/10.1038/s41586-018-0361-2
[8] Jiao, L., Song, X., You, C. *et al.* AI meets physics: a comprehensive survey. *Artif Intell Rev* **57**, 256 (2024) https://doi.org/10.1007/s10462-024-10874-4

based models and thermodynamics-inspired diffusion models used in generative AI[9]. Physics also underpins the development of energy-efficient hardware for AI such as optical[10] or neuromorphic computing[11].

Data is the fuel of AI, and physics has large datasets (for example, in high-energy physics, astrophysics, nuclear physics and materials science) and a rigorous methodology has been developed to curate, archive and analyse them. Physics data, for which there is a good understanding of the generating functions and the symmetries and conservation laws obeyed, can be used as a "sandbox"[12] to systematically evaluate and fine-tune AI models and hence contribute to the development of AI. Lastly, physicists contribute to the AI workforce as suggested by employment data (see Appendix Workforce) and success stories[13].

Physics needs AI

Data-intensive applications. AI methods play a major role in fields that acquire, process and analyse very large amounts of data such as high-energy and nuclear physics and astrophysics. The data volumes generated by experiments and astrophysical observations are comparable to the traffic experienced by some of the most prominent commercial players[14,15]. For some applications in these disciplines, be it fast data acquisition and pre-processing or data analysis, the use of AI is not a choice, but a necessity.

Computing-intensive applications. Physics has traditionally been a heavy-user of high performance computing[16]. Molecular physics, condensed matter physics, cosmology, climate physics, particle and nuclear physics among others use large, computing-intensive simulations that can be enhanced with AI methods. Examples of

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[9] Quanta Magazine (2023) https://www.quantamagazine.org/the-physics-principle-that-inspired-modern-ai-art-20230105/

[10] McMahon, P.L. The physics of optical computing. *Nat Rev Phys* **5**, 717–734 (2023) https://doi.org/10.1038/s42254-023-00645-5

[11] Marković, D., Mizrahi, A., Querlioz, D. *et al*. Physics for neuromorphic computing. *Nat Rev Phys* **2**, 499–510 (2020) https://doi.org/10.1038/s42254-020-0208-2

[12] Thais, S. Physics and the empirical gap of trustworthy AI. *Nat Rev Phys* **6**, 640–641 (2024) https://doi.org/10.1038/s42254-024-00772-7

[13] APS News (2023) https://www.aps.org/apsnews/2023/09/searching-higgs-prepared-physicist-ai

[14] Clissa, L., Lassnig, M., Rinaldi, L. How big is Big Data? A comprehensive survey of data production, storage, and streaming in science and industry, *Front. Big Data* **6** (2023) https://doi.org/10.3389/fdata.2023.1271639

[15] Accelerated AI Algorithms for Data-Driven Discovery https://a3d3.ai/about/

[16] Dongarra, J., Keyes, D. The co-evolution of computational physics and high-performance computing. *Nat Rev Phys* **6**, 621–627 (2024) https://doi.org/10.1038/s42254-024-00750-z

computationally challenging problems that benefit from machine learning approaches include lattice quantum chromodynamics[17] and cosmological simulations[18].

Experimental design and automation. Physics experiments can be very complex ranging from large particle accelerators and underground detectors to space probes and underwater sensors. AI is also helping optimize experimental setups, automating tasks or controlling experimental settings[19,20]. Robotics applications are being explored for extreme environments such as fission and fusion reactors[21] and particle accelerators.

Lastly, AI is expected to help researchers write and document code, search and summarize scientific literature and write research articles and other research outputs.

AI for physics and physics for AI

Physics has been an early-adopter and heavy user of and contributor to the field of AI. As such physics is one of the drivers of AI. AI methods are used in most fields of physics in all aspects of research. As such physics is one of the beneficiaries of AI.

Context of this Pathfinder report

The Institute of Physics (IOP) Business Innovation & Growth (BIG) Group submitted a proposal for the IOP to carry out an impact project[22] on Physics and AI which was taken forward as an IOP Impact Project Pathfinder (IPP). The aim of this IPP is better understand the challenges and opportunities around physics and AI, identify and engage with key stakeholders and develop a pathway for impact. More information about this IPP can be found at https://www.iop.org/strategy/science-innovation/physics-and-ai-impact-project-pathfinder

Evidence for this work has been gathered through a survey of the IOP members and a workshop with members and other experts from the wider physics community in academia and business. The methodology and results are described in the following

[17] Cranmer, K., Kanwar, G., Racanière, S. *et al.* Advances in machine-learning-based sampling motivated by lattice quantum chromodynamics. *Nat Rev Phys* **5**, 526–535 (2023) https://doi.org/10.1038/s42254-023-00616-w
[18] https://dirac.ac.uk/2024/05/02/flamingo-calibrating-cosmological-simulations-using-machine-learning/
[19] Edelen, A., Huang, X. Machine Learning for Design and Control of Particle Accelerators: A Look Backward and Forward, *Annual Review of Nuclear and Particle Science* **74**,557-581 (2024) https://doi.org/10.1146/annurev-nucl-121423-100719
[20] Baydin, A. G., et al. Toward Machine Learning Optimization of Experimental Design. *Nuclear Physics News*, **31**, 25–28(2021). https://doi.org/10.1080/10619127.2021.1881364
[21] UKAEA Remote Applications in Challenging Environments https://race.ukaea.uk/
[22] IOP Science & Innovation https://www.iop.org/strategy/science-innovation

sections. The aim was to understand the use of AI in physics, the views physicists hold regarding AI and identify the challenges and opportunities for AI to further contribute to physics research and innovation and how physics can further contribute to the advancement and adoption of AI. This Pathfinder report identifies specific opportunities for further action and will inform IOP's decision around whether this work will progress to a full Impact Project. We invite the physics community to read the report and engage with the IOP if there are further points that should be considered or opportunities that have not been highlighted. If you would like to provide any additional views or evidence – please contact us scienceandinnovation@iop.org

Insights from the IOP community

Survey summary

The survey ran September-October 2024 and 700 people responded. The survey looked at the level of experience with AI and views on AI (a list of questions can be found in the Appendix Survey questions). Of the 700 complete responses, 90% of respondents were IOP members, 43% were at a senior career stage, 71% self-identified as male and 14% considered themselves expert in at least one AI-related technology. Of the respondents 40% are academics and 30% work in the private sector.

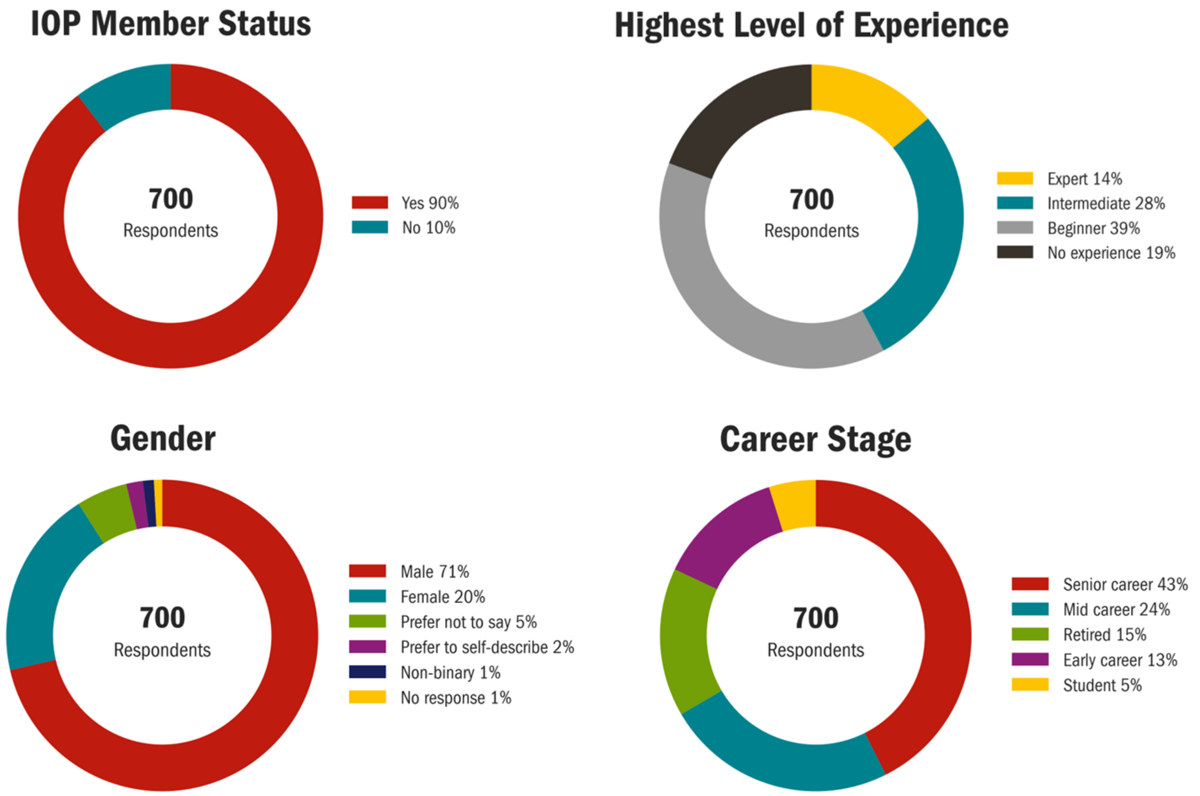

Figure 1 Respondents to the Physics and AI survey, September-October 2024.

Unsurprisingly, the top three physics topics of interest were mathematical and computational physics, astronomy and astrophysics, and particle and nuclear physics, the latter being data-intensive fields.

To the question *Do you think that AI offers potential benefits to physics research and innovation?* 75% of the respondents answered yes, a view that doesn't change much across physics disciplines and career levels but rises to 83% for those who have used AI in their roles. For context, in a 2023 survey[23] conducted by ONS, 32% of people in the UK agreed or strongly agreed that AI will benefit them (2024 data[24] shows 36%).

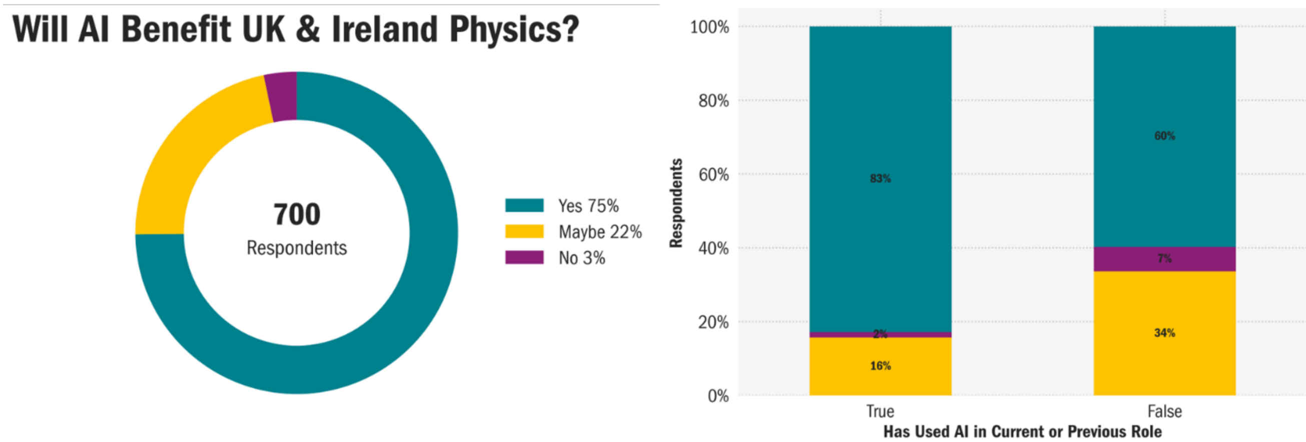

Figure 2 Do you think that AI offers potential benefits to physics research and innovation?

To the question *Do you think that the use of AI carries any concerns to physics research and innovation?* 69% of the respondents answered yes, a view that doesn't change dramatically across age groups, career levels, physics disciplines, economic sectors, and levels of expertise with AI-related technologies.

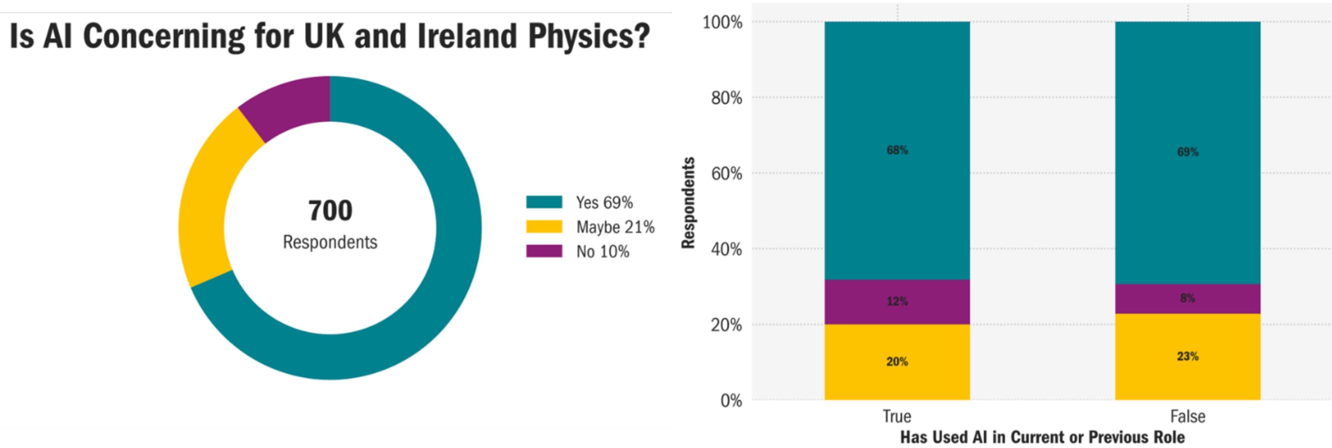

Figure 3 Do you think that AI carries any concerns to physics research and innovation?

Top uses of AI are in data analysis, simulation and writing code/documentation, which does not change much across physics disciplines or age groups. For 44% of the respondents AI is peripheral to their role, and for 16% it is central to their role. For

[23] ONS Public awareness, opinions and expectations about artificial intelligence: July to October 2023 https://www.ons.gov.uk/businessindustryandtrade/itandinternetindustry/articles/publicawarenessopinionsandexpectationsaboutartificialintelligence/julytooctober2023
[24] ONS Public opinions and social trends, Great Britain: artificial intelligence (AI) by personal characteristics https://www.ons.gov.uk/businessindustryandtrade/itandinternetindustry/datasets/publicawarenessopinionsandexpectationsaboutartificialintelligence

Registered charity no. 293851 (England & Wales) and SCO40092 (Scotland)

context, in the survey conducted by ONS, 25% of people in UK used AI in their work or education in the past 12 months. Note that the ONS data shows that only 17% of people answered often or always to the question *How often do you think you can recognise when you are using AI?* In contrast, due to the top uses of AI, our respondents are likely more able to recognize when they are using AI in their work.

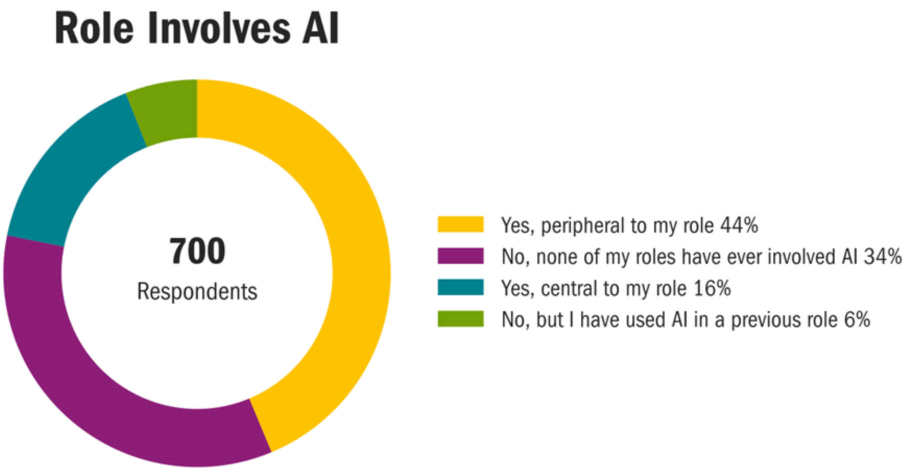

Figure 4 Does your role involve the use of AI?

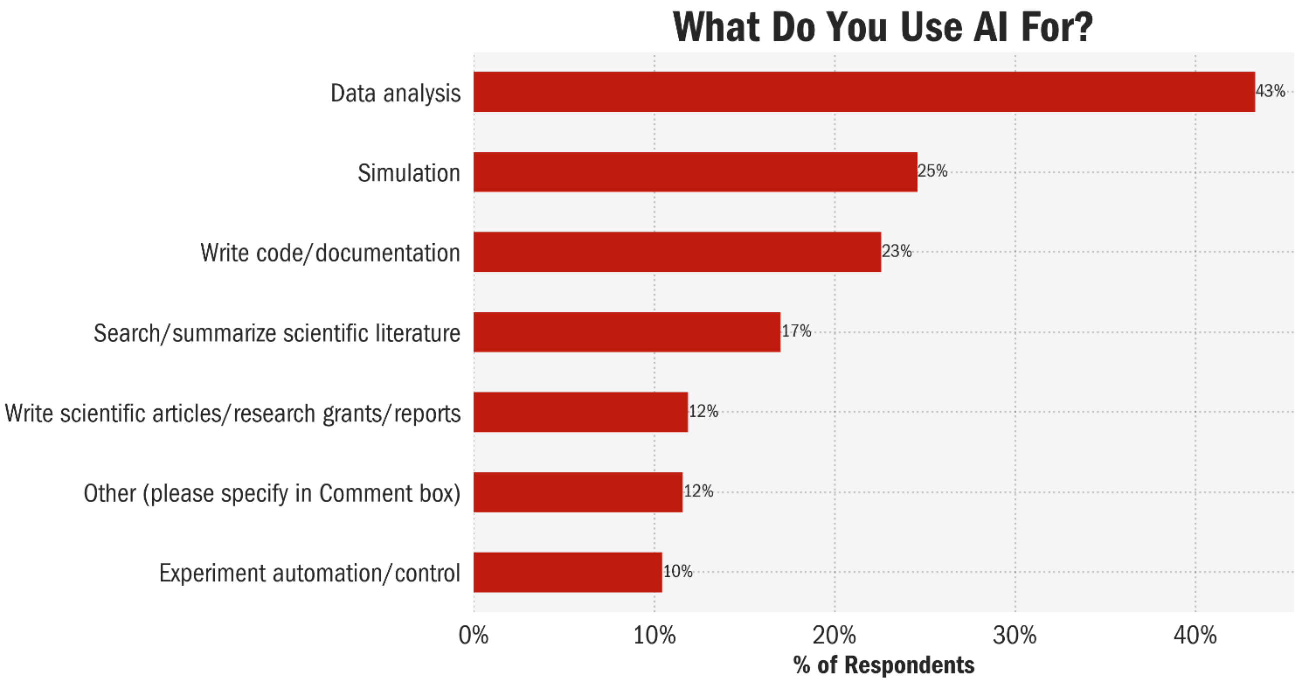

Figure 5 If you use AI in your role and/or elsewhere, what types of tasks do you use it for? (multiple answers allowed)

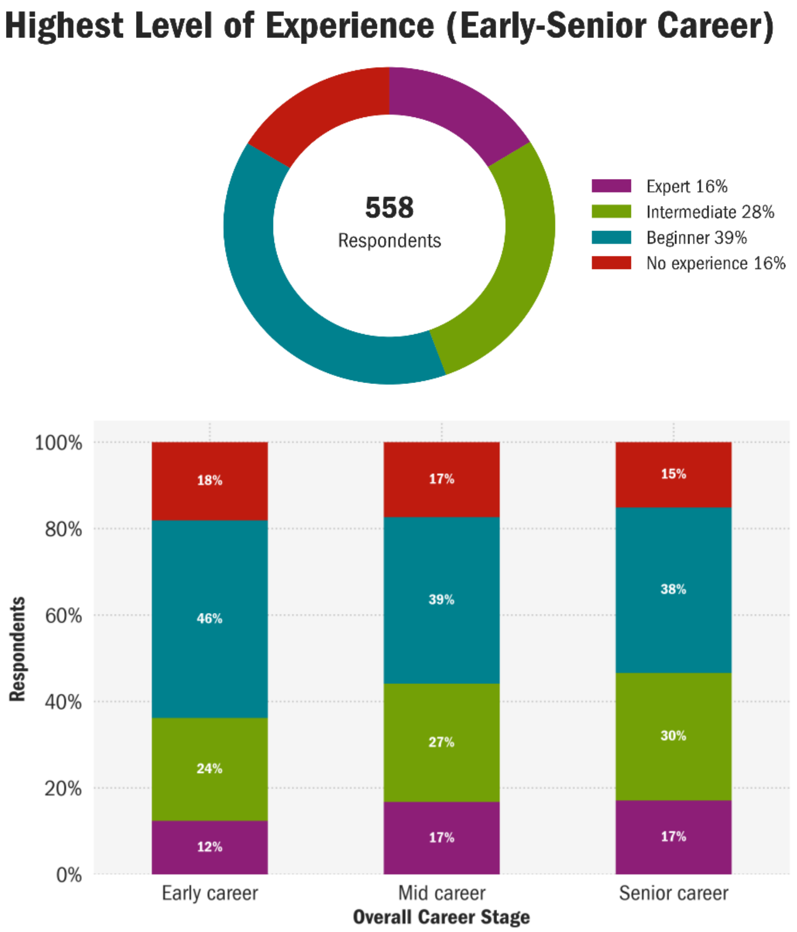

Figure 7 Highest levels of experience with AI technologies.

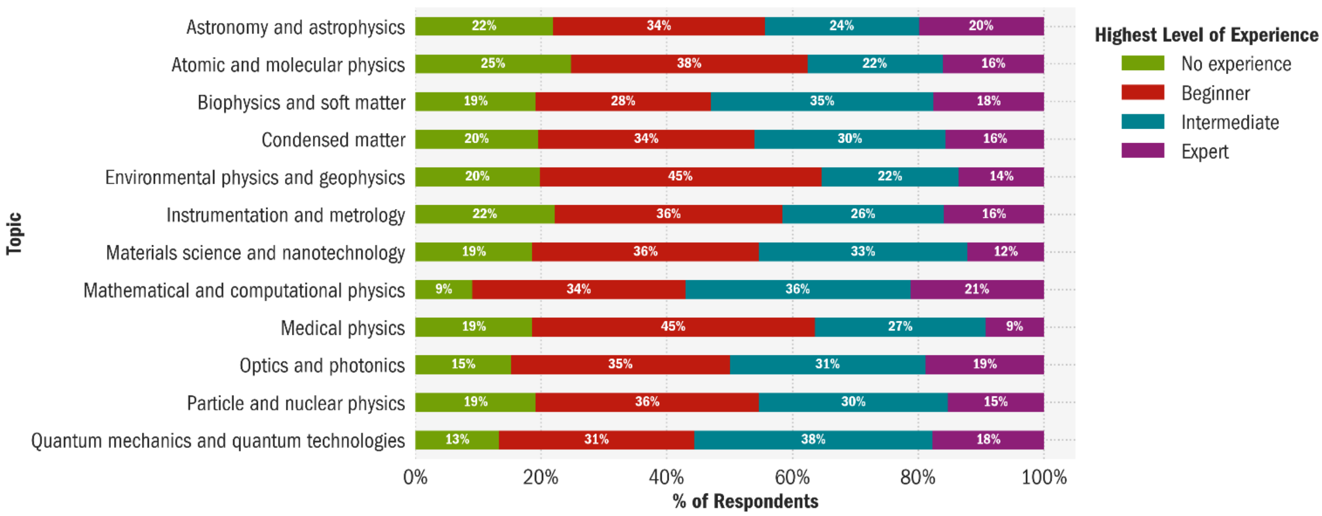

Figure 6 Breakdown of levels of experience by area of physics.

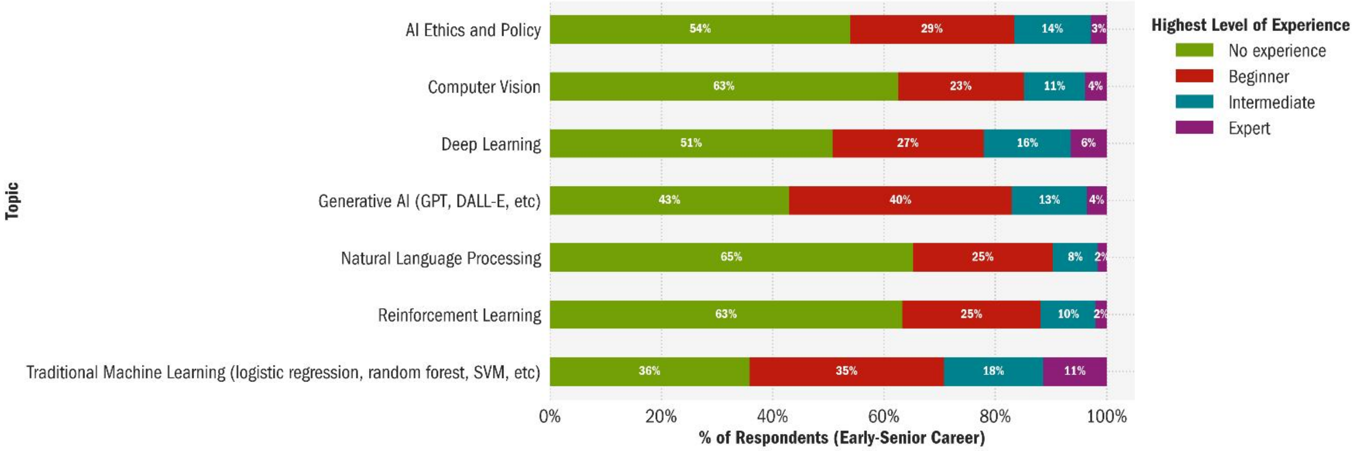

Figure 8 Breakdown of levels of experience by AI topics.

The levels of experience with AI (in particular, that 66% of respondents have used AI at some point) should be interpreted with caution. Physicists are clearly not experts in all areas of AI, and this can be seen in the breakdown of the levels of experience with different AI tools. Unsurprisingly, physicists are most familiar with traditional machine learning, which they are likely using in doing research, because these are long-established methods in different branches of physics. However, the second-highest familiarity appears to be with Generative AI, which is likely to be used very differently, due to its recent, wide availability through different commercial services. A survey[25] on 4,946 researchers worldwide highlights how scientists use generative AI, predominantly in manuscript-preparation tasks, data collection and processing and reviewing published literature. A report[26] produced by Elsevier finds that across disciplines 16% of researchers use AI extensively.

[25] Wiley (2025) https://www.wiley.com/en-us/ai-study
[26] Research Futures 2.0 Report, Elsevier (2022) https://www.elsevier.com/connect/research-futures-2022

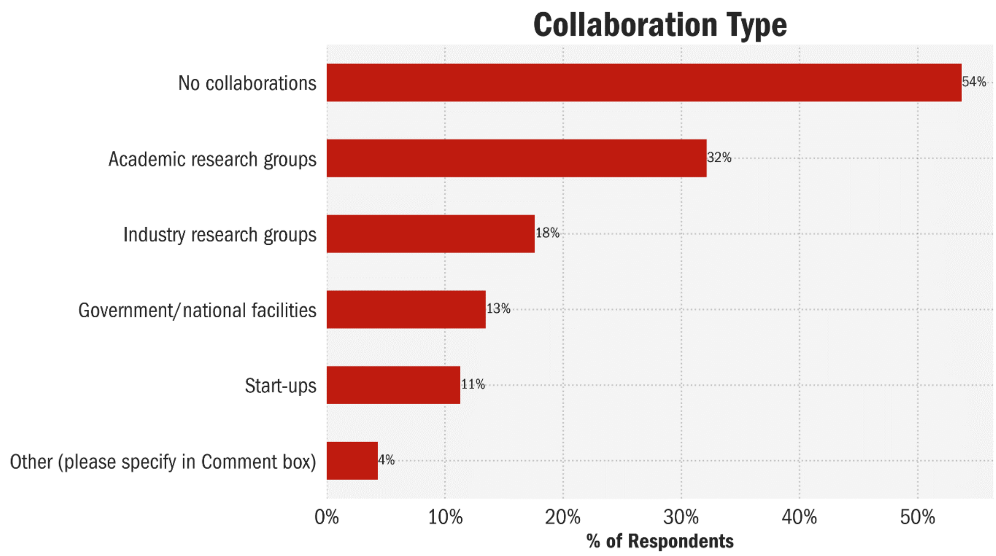

Figure 9 Do you collaborate on AI-related projects? (multiple answers allowed)

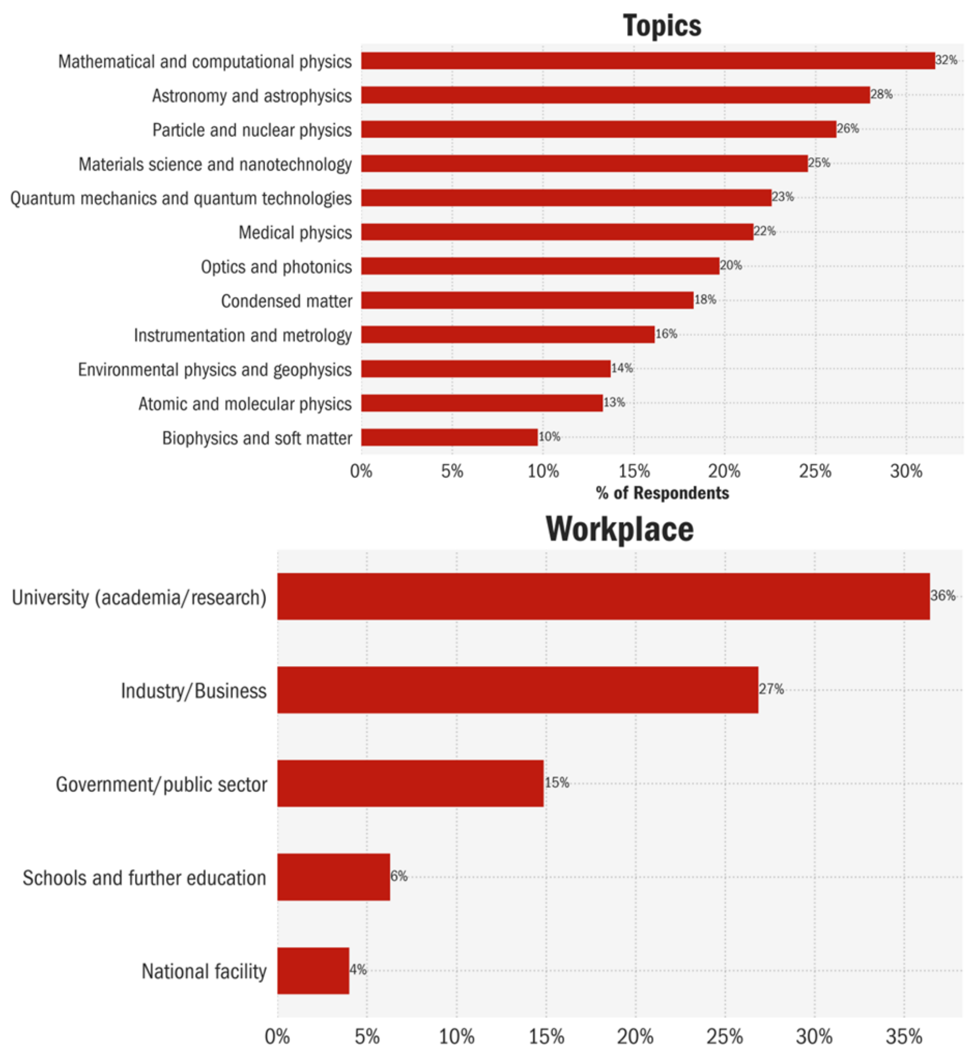

Figure 10 Physics topics of interest and current workplace of the respondents.

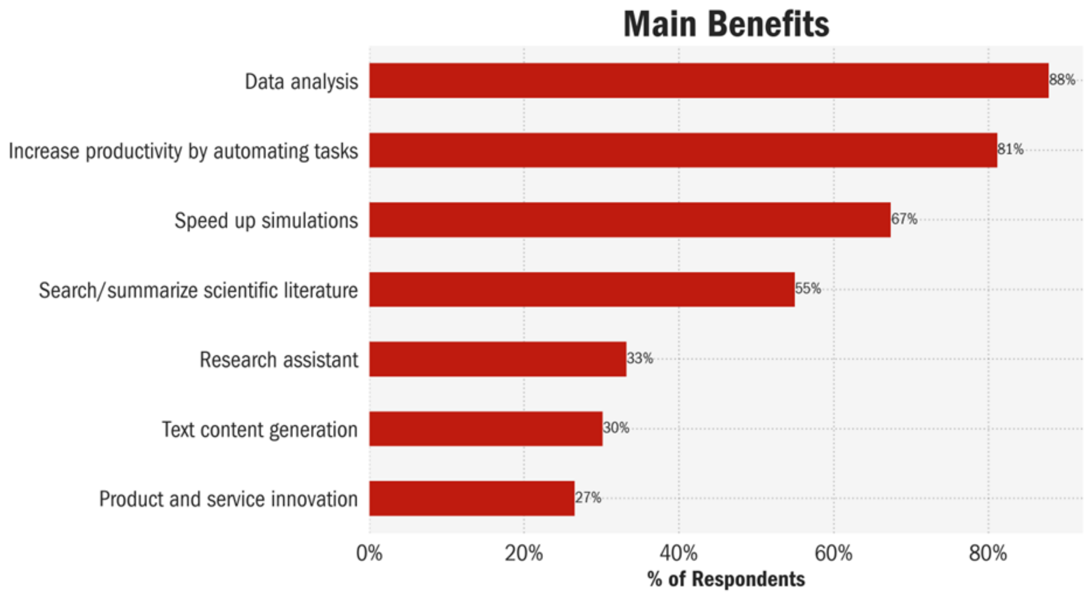

Figure 11 Where do you think AI might offer greatest potential benefit in physics research and innovation? (multiple answers allowed)

These responses broadly align with the findings of a *Nature* survey[27] of >1,600 researchers around the world where the main benefits of generative AI were seen in productivity, writing code, summarization and text generation. Another survey[28] was completed by 300 ERC grantees looks at the potential opportunities and benefits, but the responses are harder to compare. However, the ERC survey found that researchers in physical sciences saw a benefit in AI enabling the faster development of prototypes (84% rating it as 'highly likely' or 'likely').

[27] AI and science: what 1,600 researchers think, *Nature* (2023) https://www.nature.com/articles/d41586-023-02980-0

[28] Foresight: Use and impact of Artificial Intelligence in the scientific process, ERC (2023) https://erc.europa.eu/sites/default/files/2023-12/AI_in_science.pdf

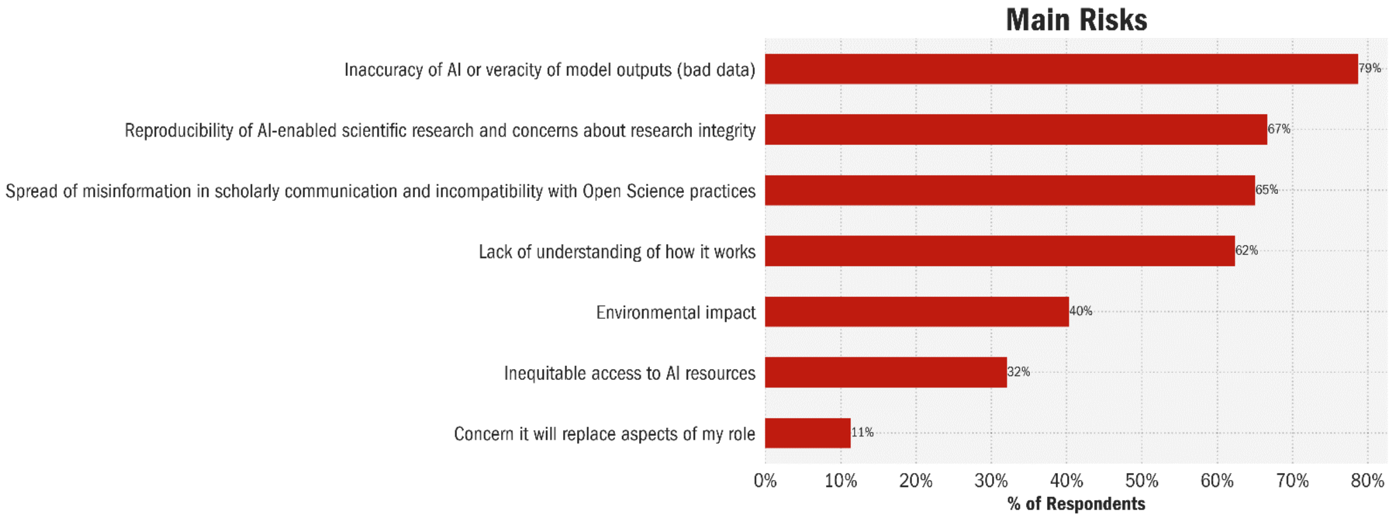

Figure 12 Which are your potential greatest concerns regarding AI in physics research and innovation? (multiple answers allowed)

These responses broadly align with the findings of a *Nature* survey of >1,600 researchers around the world which found among the main problems associated with the use of generative AI misinformation and research integrity. The ERC survey looked at the challenges and risks, also identifying misuse, lack of transparency and replicability, researchers in physical sciences, being most concerned with the latter and also with concentration of AI resources and development outside the European Union.

From the free text comments, the following concerns came across as important.

- AI changes the way research is done (*"I have strong reservations - while there is much potential benefit, we also lose a lot - in certainty and repeatability of results for starters, without which we don't have 'science' anymore"),*
- It can lead to a loss of critical thinking and physical understanding *("Loss of basic understanding of physics models and too great a reliance on AI to build models rather than thinking about things from first principles. End up with a generation of 'physicists' who don't know how to do real physics."*),
- Concerns about AI's environmental impact *("Additionally, I would be highly concerned about the power usage. We physicists are very well placed to understand our precise impact on the environment, and we have a responsibility to minimise it. We therefore should avoid using more power-hungry technologies save where we are certain the benefit significantly outweighs the costs."*).

From the free text comments three other areas came across as important.

Regulation and Standards

Respondents were both pro (*"Regulation! We need to be led by competent and flexible regulation"*) and against (*"Remove all regulations"*) regulations as they saw them hindering innovation.

Training

Respondents called for a code of best practice *("Access to guidance on best practice, this is more than just skills development"; "Code of practice needs to be developed, and the current speed of technology development is overtaking the community's ability to understand the implications of AI use, understand suitable mitigation strategies (NB this is not the same as understanding "how it works"), and reach consensus about best practice"*) and for education about the limitations of AI *("Broad general education on the uses and limitations of AI so that those not directly involved in its use have realistic expectations of what it can achieve"*).

Environment

The respondents called for *"Environmentally responsible use of AI given the energy requirements"* and *"Wider recognition of the environmental / energy impact"*.

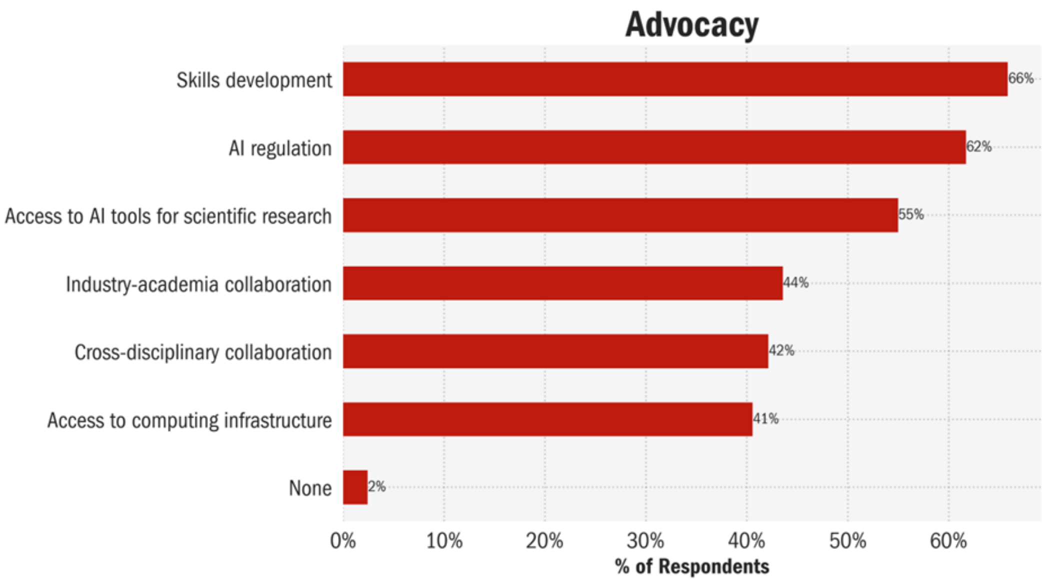

Figure 13 What areas do you see as important to make the most of AI for physics and innovation and would like the IOP to advocate for? (multiple answers allowed)

Main survey findings

97% of respondents think that AI has or might have some benefits

90% of respondents think that AI has or might have some risks

66% of respondents have used AI at some point

For 16% of respondents AI is central to their current role and for 44% AI is peripheral to their current role

25% of respondents use AI for data analysis, 14% for simulation and 13% for writing code/documentation

In general, views do not change much across age groups, career levels, physics disciplines, economic sectors, and levels of expertise with AI-related technologies.

Workshop summary

A one-day landscaping workshop was held at the IOP on 19th November 2024 bringing together representatives from academia and industry. Forty participants joined on the day. A roadmapping framework was used to support a plenary structured brainstorm to develop a landscape. This was followed by short small-group discussions to capture suggestions of organisations who would be appropriate to engage in taking forward priority opportunities and highlight the potential role of the IOP. The workshop attendees had varied backgrounds (See Appendix

Workshop), but not all areas of physics and industry sectors were covered. This is reflected in how the landscape was populated by the participants.

Methodology

Workshop participants used the framework in the table shown below to brainstorm ideas of Trends and Drivers, Innovation Opportunities, and Physics Research and Enablers relevant for Physics and AI. Trends included: sociological, technological, economic, environmental, political, legislative and ethical trends. These were complemented by industry trends and needs for different sectors and physics discipline trends and needs. Physics research enablers included R&D (Physics research, research in AI and other research), policy, standards, skills and education, infrastructure, finance/investment, relationships/collaborations and others. The timeframes used were short-term (1 year), medium-term (2 years), and long-term (5 years). Ideas were captured on sticky notes, with similar ideas clustered under headings, and then participants voted on the most important items in each of the three main layers.

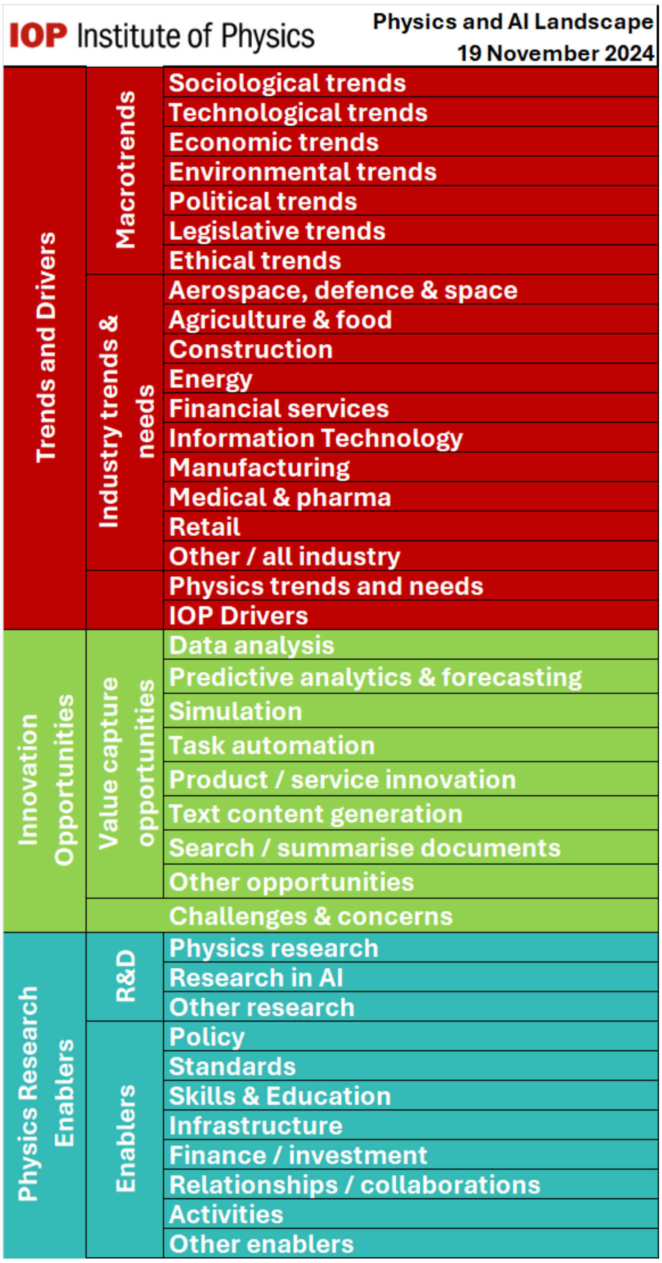

Figure 14 Framework used by the workshop participants for the discussions.

During the structured brainstorm for the landscape, participants were asked to link ideas in subsequent layers to priority ideas in the layer above. In this way connections were made between the innovations and solutions required to address the trends and drivers, and the research and enablers required to develop and deliver the innovations and solutions. The visual linkages are shown in ‘heat-map’ format, with stronger linkages indicated by deeper colour. The strength of linkage is generated by the number of times participants indicated a link in their contributions. Note that post-workshop some of the ideas were moved to different layers and clusters, and so the linkages of these items were not transferred.

Once the landscape had been generated and key ideas prioritised, the participants reviewed the list of priority innovation opportunities and challenges in plenary to consider which they would explore in small groups and if there were any key gaps or concerns. The linkage tables can be found in the Appendix Workshop.

The framework used for the landscape was well populated across the three main layers and the three main timeframes. Sublayers which were not populated included economic, political, and legislative trends, and some industry sectors, such as aerospace, defence and space; information technology, and retail. The product and service sublayer was not populated within the innovation opportunity layer -potentially an aspect which would be most pertinent within a specific industry sector focus, or a commercial organisation. The gaps in population could be an artifact of the knowledge or focus of expertise of the participants present in the workshop. It may be useful to engage with experts in the industries highlighted to understand if there are key trends and needs which should be captured.

In general, there seemed to be good consensus on the innovation opportunities with the highest potential to take forward. Many of these could be realised in the short- and medium-term and address value capture opportunities across data analysis, simulation, predictive analytics and forecasting, task automation, and other opportunities, such as physics-informed AI.

Trends and Drivers – why

Key physics trends include an increasing need to learn from and process large and complex data; simulation of complex physical processes / surrogate models; building symmetries and physics into AI models and accelerated chemistry and material science workflows, high performance computing, density functional theory methods. Relevant technological trends in the medium term include new algorithmic advancements and learning paradigms such as neural operators; with longer term ambitions for more efficient/low power computing technology, such as neuromorphic computing; and a vision of more efficient computing paradigms. Industry trends include opportunities for improving automation and productivity; medical and pharma in silico modelling, faster and more efficient drug design and discovery, and growth of multimodal personalised medicine; optimising energy provision and grid management; manufacturing optimization and decision-making strategies; the ability to improve predictive maintenance through combining data from multiple sources; and the need for faster weather forecasting across a number of industry sectors. Other relevant macrotrends include a current ethical AI focus and the need for ethical regulation and policies to catch-up with AI developments; the need for increased education and awareness of AI, and the climate crisis needing effective computational solutions.

ID	Trends and Drivers	Landscape Layer	Time	Votes	%
TD01	Increasing need to learn from and process large and complex data	Physics trends & needs	ST-MT	27	13%
TD03	Simulation of complex physical processes / surrogate models	Physics trends & needs	ST-MT	24	11%
TD04	More efficient/low power computing technology - neuromorphic computing	Technological trends	LT	18	9%
TD05	Trend to build symmetries and physics into AI models	Physics trends & needs	MT-LT	17	8%
TD06	Accelerated chemistry and material science workflows, HPC, DFT methods	Physics trends & needs	MT	16	8%
TD07	New algorithmic advancements and learning paradigms such as neural operators	Technological trends	MT	15	7%
TD08	Renewed focus on safety and trust ethics	Ethical trends	MT-LT	11	5%
TD09	Ethics regulation needs to catch up with AI developments	Ethical trends	ST-MT	11	5%
TD10	Opportunities for improving automation and productivity	Other / all industry	MT	11	5%
TD11	In silico modelling of drug design and complex/rare diseases	Medical & pharma	ST-MT	10	5%
TD12	Need for education, awareness and understanding of AI	Sociological trends	ST	9	4%
TD13	Computing paradigms will evolve to be more efficient	Technological trends	V	9	4%
TD14	Multimodal personalised medicine is growing	Medical & pharma	MT-LT	7	3%
TD15	Need to optimise energy provision and manage increasing grid complexity	Energy	ST	6	3%
TD16	Opportunities for faster and more efficient drug design / discovery	Medical & pharma	ST-MT	6	3%
TD17	SDGs and climate crisis need effective computational solutions	Environmental trends	ST-LT	5	2%
TD18	Combine data from multiple sources for better predictive maintenance / fault detection	Other / all industry	ST-MT	5	2%
TD19	Optimization and decision-making strategies in manufacturing	Manufacturing	MT	2	1%
TD20	Need for faster weather / climate forecasting for different sectors	Other / all industry	ST	1	0%

Innovation Opportunities – what

There were several innovation opportunities thought to be directly related to physics. Key was ‘physics-informed AI’ to leverage physics knowledge and approaches to improve AI methods and results and ‘learning from equations’. Ideas to use AI to improve physics included simulation and task automation opportunities, namely transferring existing multimodal AI research to physics use cases, machine learning of interatomic potentials and a general-purpose platform for AI simulation; design of experiments with AI and harnessing AI to enable scientists to focus on science. Other innovation opportunities included developing uncertainty quantification methods using neural network technology, neural network representation of large datasets, feature explanation techniques, agentic AI, causal models multi-fidelity learning, smaller scale application specific AI, and reduced order modelling. A medium-term challenge is ensuring data generated and used for training is reliable. In the longer term, there is a need for explainable and interpretable AI at different resolutions. Several of these opportunities and challenges were explored in more depth by smaller groups in a table exercise.

ID	Innovation Opportunities	Landscape Layer	Time	Opportunity Votes	%	Feasibility Votes	%
IN01	Physics-informed AI	Other opportunities	ST-MT	29	10%	24	15%
IN45	Explainable & interpretable AI at different resolutions	Other opportunities	LT	25	9%	0	0%
IN02	Challenge: ensuring generator to training data is reliable	Challenges & concerns	MT	21	8%	12	8%
IN03	Develop UQ methods using AI NN technology	Data analysis	ST-MT	19	7%	21	13%
IN04	Transfer existing Multimodal AI models to physics	Simulation	ST	19	7%	18	11%
IN05	Bayesian optimization / experimental design	Task automation	ST	17	6%	17	11%
IN06	Harnessing AI to enable creative focus on science	Task automation	ST	17	6%	16	10%
IN08	Neural network representation of large datasets	Simulation	ST	17	6%	9	6%
IN09	Learning from equations - e.g. using neural networks as optimizers	Data analysis	ST-LT	16	6%	17	11%
IN10	Multifidelity learning - high- & low-quality data processing	Other opportunities	ST-MT	16	6%	14	9%
IN11	General purpose platform for AI simulation	Simulation	ST	15	5%	11	7%
IN12	Feature explanation techniques	Data analysis	ST	14	5%	0	0%
IN13	Agentic AI	Other opportunities	ST-MT	12	4%	0	0%
IN14	Smaller scale application specific AI	Other opportunities	ST-MT	12	4%	0	0%
IN15	Causal models	Simulation	ST	10	4%	0	0%
IN16	Machine learning of interatomic potentials	Predictive analytics & forecasting	ST-LT	10	4%	0	0%
IN17	Reduced order modelling	Simulation	ST-MT	10	4%	0	0%

Physics research and Enablers – how

The key enablers identified did not highlight research required but focused across several other enablers. Industry-academia collaboration was seen to be an important enabler with several different mechanisms suggested to incentivise this, and proposals for guidelines and platform to enable this. There is a need for various forms of skills development and education in AI for physics so that physicists have a greater understanding of the potential and application of AI. To support knowledge sharing, facilitating a Physics AI community would be valuable. More generally, early-stage education on AI and accreditation /certification around the application of AI would be helpful.

Note that the above enablers have also been highlighted in the survey.

Interdisciplinary research funding and incentives such as hubs and ‘grand challenges’ would leverage insights across different disciplines, enabling realisation of the applied value of AI. Standards for data sharing and appropriate data infrastructure would also support this collaborative working and learning. In terms of policy, there is a need for an appropriate regulatory framework, which addresses both the need to support innovation and take a risk-informed approach. Policy should also support sustainable software development and sharing. Infrastructure would include varied and comprehensive computational resources as well as innovation spaces and regulatory sandpits to enable experimentation in a ‘safe space’.

ID	Physics Research Enablers	Landscape Layer	Time	Votes	%
PR01	Incentivising industry academia collaboration	Other enablers	ST-MT	32	13%
PR02	Skills development and education in AI for physics	Skills & Education	ST-LT	26	10%
PR03	Interdisciplinary research funding and incentives	Finance / investment	ST-MT	25	10%
PR04	Data infrastructure storage, access, and sharing standards	Standards	ST-LT	20	8%
PR05	Appropriate regulatory framework.	Policy	ST-LT	18	7%
PR06	Physics AI community	Relationships / collaborations	ST-MT	17	7%
PR07	Varied and comprehensive computational resources	Infrastructure	ST-MT	16	6%
PR08	IOP to facilitate access to good practice framework for AI application	Activities	ST-MT	16	6%
PR09	Incentivising sustainable software development and sharing	Policy	ST-MT	15	6%
PR10	Innovation spaces and regulatory sandpits	Infrastructure	ST	30	12%
PR11	Guidelines and platform for industry-academic collaboration.	Policy	MT-LT	12	5%
PR12	More accessible overseas talent visa.	Skills & Education	ST	10	4%
PR13	Early-stage education on AI	Skills & Education	MT-LT	10	4%
PR14	Accreditation /certification around application of AI	Skills & Education	MT	9	4%

Innovation Opportunities linked to Trends and Drivers

The priority innovation opportunities and solutions all link to multiple trends and drivers, and all the priority trends and drivers have innovation opportunities suggested to address them. The increase in volume and complexity of data, and the need for simulation of complex physical processes both require numerous innovation solutions. Multiple innovation opportunities also address the focus on safety and trust ethics and the potential for in silico modelling. Harnessing AI to enable scientists to focus on science is seen as an opportunity to address all of the trends and drivers. Physics-informed AI has very strong links to multiple trends and drivers. Learning from equations and multifidelity learning are also strongly linked to acceleration of science workflows and new algorithmic advancements.

Physics research and Enablers linked to Innovation Opportunities

As mentioned previously, the main identified enablers for the innovation opportunities sit outside Physics and Research. The majority of enablers highlighted are seen to underpin all of the priority innovation opportunities, although skills development and education for AI in physics, interdisciplinary research funding and incentives, and varied and comprehensive computational resources are strongly linked across a high number of opportunities. As a corollary, innovation opportunities are also seen to benefit from large numbers of enablers.

Findings

The key opportunities and challenges identified can be seen to impact most of the physics disciplines considered. There are strong scientific and economic potential impacts, cutting across the majority of industry sectors, with particularly strong links to aerospace, defence and space; energy; manufacturing; medical and pharma industry[29] sectors highlighted. Reflecting on the outputs, there are some common suggestions for action from the IOP to support several of the innovation opportunities or address the key challenges.

- **Providing mechanisms to connect industry and academia** – such as workshops or special issues – were suggested for physics-informed AI, experimental design, harnessing AI, and multifidelity.
- **An IOP special interest group relating to AI** – potentially on uncertainty quantification, ML, or how to harness AI for scientific focus.
- **Making training or promotional resources accessible** – curating training material or providing resources for people to promote AI inside their own organisations; provide professional accreditation.
- **Communication and raising awareness tailored for different audiences** – through advertising and lobbying, facilitating discussions and workshops, and providing a platform with IOPP – to address several of the innovation opportunities and current challenges.

Note that collaboration academia-industry and skill development/training have also been highlighted in the survey.

Infrastructure

Two types of infrastructure have been identified at the workshop:

- **Computational resources**

The need to access computational resources has also been highlighted in the survey. The workshop discussions did not dwell into details on the infrastructure requirements, beyond describing them as varied and comprehensive. Some ideas suggested by the participants included: access to a large volume of dedicated GPU resources, more compute infrastructure to generate simulation data, access to a national computational infrastructure for physics-AI, data storage capacity close to large computers. In the long-term, large-scale neuromorphic facilities and investment in alternative chips were also mentioned.

The JENA White Paper on European Federated Computing[30] recommended two options: the establishment of a centralized, large-scale GPU facility that consolidates resources across countries and institutions or expanding existing high-performance

[29] Coming from the table discussions of priority opportunities (see Appendix Workshop).

[30] JENA White Paper on European Federated Computing, Chapter 5 (2025) https://nupecc.org/jenaa/docs/JENA_comp_white_paper.pdf

computing infrastructures across multiple institutions, by increasing GPU availability and integrating cloud-based solutions with on-premises system.

The 2022 Review of the Digital Research Infrastructure for AI[31] highlighted that Physics along with Computer Science and Engineering were particularly strongly represented in the survey, so the findings of this report should be highly relevant.

- **Data sharing infrastructure: storage, access and sharing standards**

Ideas from the workshop participants included: financial and policy incentives for data generation and storage, for data and code sharing/attribution and versioning, regulation for traceable data and processes and standardisation to enable inter-operability and sharing. The need for an infrastructure for data storage and retrieval at fast speed and with fair access was also highlighted.

The JENA White Paper also recommended the establishment of a scalable data infrastructure initiative by creating shared repositories and tools and developing platforms for distributed workloads.

Note that the AI Opportunities Action Plan[32] published in January 2025 discussed the need for developing "a long-term compute strategy that will ensure the UK has the AI infrastructure and compute capacity it needs to deliver new scientific innovations and discoveries" and the creation of a National Data Library. Points that echo the issues raised by the workshop participants include recommendations to develop and publish guidelines and best practices for releasing open government datasets; actively incentivise and reward researchers and industry to curate and unlock private datasets.

Skills

A need for skills development and education on AI for physics was highlighted by both survey and workshop. Specifically, from the workshop several points were identified:

- **Accreditation /certification around application of AI**. Ideas included: professional training how to apply AI; provision of chartered data scientist qualification; foundation in software engineering, data management, etc in all undergraduate courses; (IOP) create an MPhys PhD, etc. 'data' suffix certification that helps recognise a professional qualification in data literacy. This last point was also mentioned in the survey ("Conferences, discussion forums, support of the chartered data scientist qualification being set up by the association of data scientists within IOP.")

[31] Review of the Digital Research Infrastructure for AI (2022) https://www.turing.ac.uk/sites/default/files/2022-09/ukri-requirements-report_final_edits.pdf
[32] Department of Science, Innovation and Technology, AI Opportunities Action Plan (2025) https://www.gov.uk/government/publications/ai-opportunities-action-plan/ai-opportunities-action-plan

- **Early-stage education on AI**. Ideas included: AI education from an early stage; Teaching AI concepts and responsible usage in schools; Extend teaching coding to pupils in schools.
- **More accessible overseas talent visa**.
- **Skills development and education in AI for physics**. Ideas included: AI literacy as part of core education in the physical sciences; AI education schemes for senior academics; training and physics (CDTs, apprenticeships) in AI and large experiments or simulations; cross-departmental doctoral training; include software engineering, computer science and physics in interdisciplinary foundation courses; basic shared minimum level of programming literacy (Python, Pytorch Hardware /GPU acceleration)

Note that the AI Opportunities Action Plan echoed similar points (Support Higher Education Institutions to increase the numbers of AI graduates and teach industry-relevant skills; increase the diversity of the talent pool; expand education pathways into AI; ensure its lifelong skills programme is ready for AI; explore how the existing immigration system can be used to attract graduates from universities producing some of the world's top AI talent).

Insights from other scientific communities

The current work is the first to look at the specific needs of the physics community as a whole. Different reports from the Royal Society, the National Academies in the US[33] and the European Commission[34,35] have discussed at length AI for science and scientific discovery, but in these works the differences between various fields of science were not considered in detail; physics was part of the physical sciences and was only mentioned separately in some examples.

The JENA communities—ECFA (European Committee for Future Accelerators), NuPECC (Nuclear Physics European Collaboration Committee), and APPEC (Astroparticle Physics European Consortium) together with EuCAIF (European Coalition for AI in Fundamental Physics) produced a White Paper[36] on the AI Infrastructure for

[33] AI for Scientific Discovery: Proceedings of a Workshop, National Academies (2024) https://nap.nationalacademies.org/read/27457/chapter/1
[34] Foresight: Use and impact of Artificial Intelligence in the scientific process, ERC (2023) https://erc.europa.eu/sites/default/files/2023-12/AI_in_science.pdf
[35] Successful and timely uptake of Artificial Intelligence in science in the EU, European Commission (2024) https://op.europa.eu/en/publication-detail/-/publication/d6d8ed54-32a8-11ef-a61b-01aa75ed71a1/language-en
[36] Gert Aarts et al. Strategic White Paper on AI Infrastructure for Particle, Nuclear, and Astroparticle Physics: Insights from JENA and EuCAIF (2024).

Particle, Nuclear, and Astroparticle Physics. In the US, similar community input was provided for the Study on the Future of Particle Physics (Snowmass)[37,38].

Our report sits between the high-level reports on AI for science and the community white papers representing the views of physics sub-disciplines. As such it fills a very obvious gap in the landscape of evidence for setting future policy and funding for AI for science. While our work echoes previous findings, it also uncovers physics specific insights.

Common findings

The Royal Society report[39] emphasized as future research questions:

- AI and computing infrastructures for science
- AI and the future of skills for science
- AI and environmental sustainability
- AI standards and scientific research

All these themes also came across in our survey and workshop.

The Royal Society report identified the following ways AI changes scientific research

1. Growing use of deep learning across fields
2. Obtaining insights from unstructured data
3. Large-scale, multi-faceted simulations
4. Expediting information synthesis
5. Addressing complex coding challenges

The last four align with the main benefits identified in our survey and points 2-4 were discussed in the workshop.

The DeepMind policy team put together a report[40] in which 5 opportunities to accelerate science are identified

1. Knowledge: Transform how scientists digest and communicate knowledge

2. Data: Generate, extract, and annotate large scientific datasets

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[37] Shanahan, P., Terao, K., Whiteson, D., Snowmass 2021 Computational Frontier CompF03 Topical Group Report: Machine Learning (2022) https://doi.org/10.48550/arXiv.2209.07559

[38] Harris, P. et al. Physics Community Needs, Tools, and Resources for Machine Learning (2022) https://doi.org/10.48550/arXiv.2203.16255

[39] Science in the age of AI How artificial intelligence is changing the nature and method of scientific research Royal Society (2024) https://royalsociety.org/news-resources/projects/science-in-the-age-of-ai/

[40] A new golden age of discovery: Seizing the AI for Science opportunity (2024) https://www.aipolicyperspectives.com/p/a-new-golden-age-of-discovery

3. Experiments: Simulate, accelerate and inform complex experiments

4. Models: Model complex systems and how their components interact

5. Solutions: Identify novel solutions to problems with large search spaces

The first four align with the findings of our survey and workshop in terms of potential benefits. The DeepMind report also identified 5 risks:

1. Creativity: Will AI lead to less novel, counterintuitive, breakthroughs?

2. Reliability: Will AI make science less self-correcting?

3. Understanding: Will AI lead to useful predictions at the expense of deeper scientific understanding?

4. Equity: Will AI make science less representative, and useful, to marginalised groups?

5. The environment: Will AI hurt or help efforts to achieve NetZero?

In our survey 2, 3 and 5 also came up strongly, while the survey mainly mentioned 3. In particular, in the survey's free-text comments understanding came up as an important concern.

The SAPEA report[41] identified the following opportunities and benefits for AI in science:

- Accelerating discovery and innovation (including automated idea generation from the literature, speeding up simulations, facilitating Big Data analysis, new ways of performing research and opening up new fields of research inquiry; advanced experimental control, discoveries from experimental data)
- Automating workflows
- Enhancing output dissemination

The challenges and risks

- Limited reproducibility, interpretability and transparency (reproducibility crisis, the problem of opacity)
- Poor performance (or inaccuracy) (due to poor data quality, d to failure to update the model, due to differences between training data and real-world population, due to inadequate knowledge and training)
- Fundamental rights protection and ethical concerns
- Misuse and unintended harms – Misinformation and poor-quality information
- Societal concerns

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[41] SAPEA, Successful and timely uptake of artificial intelligence in science in the EU: Evidence review report. DOI 10.5281/zenodo.10849580 https://scientifcadvice.eu/advice/artifcial-intelligence-in-science/ (2024).

All benefits and risks are echoed in the results of our survey.

Differences

In the Royal Society report concerns were raised about the role of the private sector, namely: “Private sector dominance and centralisation of AI-based science development; Overreliance on industry-driven tools and benchmarks for AI-based science; The private sector and open science.” “The increasing presence of the private sector in AI-based science funding raises concerns that industry’s influence might shift the focus from fundamental research to applied science. This shift could exacerbate the ‘brain drain’, where a significant flow of AI talent leaves academia for the private sector, driven by higher salaries, advanced resources and the opportunity to work on practical applications.” The SAPEA report did raise similar concerns regarding brain drain and “AI Big Tech companies have adopted strategies to profit from AI and dominate the AI innovation frontier. In these strategies, knowledge inflows from academia are maximised while minimising outflows through secrecy.”

Neither the survey, nor the workshop raised concerns along these lines. Concerns raised in relation with big tech related to the environmental impact. This might be because in physics there is less reliance (or a perception thereof) on industry-driven tools. However, brain-drain should have come up considering the numbers of physics graduates going into the IT industry. The brain-drain could be more dramatic for research software engineer type of roles. Survey respondents and workshop participants appeared very interested in industry-academia collaborations.

In the DeepMind report among the five identified risks are loss of creativity and equity. Neither of these came across in our survey and workshop. The reason why equity was not discussed, may be due to the perception that data used in physics is unbiased and that physics research is objective. While, in general physics data does not involve privacy issues and human subjects, there are areas such as medical physics where equity concerns should be discussed. Although the loss of creativity did not come up in our survey or concern, the loss of physical understanding was an important point that was reiterated in several free-text comments. This might have to do with the nature of physics as a discipline and the importance of having an underlying theory. The SAPEA report discussed ethical concerns but did not mention the loss of understanding as a major issue.

Future directions of inquiry

Embed physics in the government and research councils' strategy

As discussed in the beginning of the report, physics is both an enabler of the development of AI and a high-potential user of AI. There are opportunities to bring physics more closely into the overall development and delivery of the national AI strategy. There are also opportunities to use AI intelligently to accelerate and improve physics outcomes – however in previous reports about AI for science, physics opportunities have been overlooked[33-35,39,40]. More work is required to articulate these high potential AI use cases in physics, and consideration should be given to appropriate funding mechanisms – via AI for Science programs or otherwise. Physics brings a unique perspective that makes it an important case study to consider in future AI for science strategy works (see the AI Opportunities Action Plan[32] and a recent report[42]). There is a need to better articulate and showcase what AI can do for physics and what physics can do for AI.

Energy and environment

AI consumes a lot of energy. In the UK the annual electricity consumptions of data centre was 3.6 TWh in 2020 and could increase to as much as 35 TWh by 2050[43]. Sustainability[44] is a concern that came across in the survey. As highlighted out in a previous IOP report[45] physics innovation and physicists are vital to scaling up a sustainable, global green economy and a sustainable and just energy transition. The survey and workshop highlighted that physics can also contribute to the development of low-power AI.

Explainability and evaluation

Physics methodologies developed for curating, sharing and benchmarking big datasets could be useful for the evaluation of AI, for example machine learning

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[42] Tony Blair Institute, A New National Purpose: Accelerating UK Science in the Age of AI (2025) https://institute.global/insights/tech-and-digitalisation/a-new-national-purpose-accelerating-uk-science-in-the-age-of-ai
[43] NESO Data Centres (2022) https://www.neso.energy/document/246446/download
[44] National Engineering Policy Centre, Foundations for environmentally sustainable AI (2025) https://nepc.raeng.org.uk/sustainable-ai
[45] Institute of Physics, Physics Powering the Green Economy (2023) https://www.iop.org/strategy/science-innovation/physics-powering-green-economy

competitions and datasets[46,47] or scientific machine learning benchmarks[48]. Topics such as uncertainty quantification and physics-informed AI were highlighted as opportunities by our workshop participants.

Access to data and compute infrastructure

A lot of physics research is both data- and computing-intensive and therefore it requires access to the AI infrastructure. There is a need to reiterate that physics has big data and big compute needs and showcase how these go well beyond fundamental research, and are relevant to societal challenges and the economy, for example in climate modelling[49] or developing fusion energy[50].

Skills, careers and innovation

There is a clear need for skills development and education in AI for physics. Despite their familiarity with machine learning methods in research, physicists are users, not developers, and a skill gap in software engineering and AI methods for physics was identified. Physicists also contribute to the AI workforce, but the extent of the overlap is unclear and there is an increased need for non-traditional roles (such as research software engineer) and career paths. There is interest in collaborations between academia and industry.

[46] Rousseau, D., Ustyuzhanin, A. Machine Learning scientific competitions and datasets (2020) https://doi.org/10.48550/arXiv.2012.08520
[47] Bhimji, W. et al. FAIR Universe HiggsML Uncertainty Challenge Competition (2024) https://doi.org/10.48550/arXiv.2410.02867
[48] Thiyagalingam, J., Shankar, M., Fox, G. *et al.* Scientific machine learning benchmarks. *Nat Rev Phys* **4**, 413–420 (2022) https://doi.org/10.1038/s42254-022-00441-7
[49] Bracco, A., Brajard, J., Dijkstra, H.A. et al. Machine learning for the physics of climate. *Nat Rev Phys* **7**, 6–20 (2025) https://doi.org/10.1038/s42254-024-00776-3
[50] https://www.gov.uk/government/news/ibm-stfc-and-ukaea-collaborate-on-fusion-powerplant-design

Conclusion

This Pathfinder report is based on evidence gathered through a survey and a community workshop. It looks at the uses of AI in physics, the views physicists hold regarding AI and identified some of the challenges and opportunities for AI to further contribute to physics research and innovation.

This is one of the first discipline-specific investigations, as opposed to previous studies across many scientific fields. Our survey is the first that is physics-specific and UK & Ireland focused. Previous surveys have engaged scientists across multiple disciplines, with insights from the physics community aggregated under physical sciences. Studies dedicated to one field, like this one, provide nuance to the discussion about AI for science and uncover discipline-specific views and needs and offer routes to maximising impact that might otherwise be missed.

Although AI methods have been used for a long time, the physics community as a whole has yet to come together to share tools and knowledge developed in different sub-disciplines. The survey and workshop highlighted the need for more collaboration, sharing and dialogue across physics and with other fields and industry. The IOP is seen as a natural forum to foster inter-disciplinary and inter-sector dialogue and collaboration.

AI advances are fast-paced and both the AI Opportunities Action Plan[32], published in January 2025, and the Tony Blair Institute paper[42] 'Accelerating UK Science in the Age of AI', published in February 2025, highlight the importance of AI for Science for the UK. This Pathfinder report highlights the compelling reasons why the physics community should be actively involved in the AI for Science strategy. Maximising the long-standing synergies between Physics and AI will advance scientific discovery beyond physics and uncover opportunities for technological and economic growth in UK and Ireland.

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Workshop participants

Around 40 representatives from academia and industry participated in the workshop from the following organisations:

Alan Turing Institute

digiLab

IBM

Imperial College London

IOP Publishing

London Institute for Mathematical Sciences

Mach42 Ltd

Microsoft

Microsoft Research

Murgitroyd

National Physical Laboratory

Nvidia

Oxford Instruments

Software Sustainability Institute

STFC

Toshiba Europe Ltd

UKAEA

University College London

University of Bristol

University of Cambridge

University of Edinburgh

University of Hertfordshire

University of Liverpool

University of Manchester

University of Nottingham

University of Oxford

University of Sussex

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Appendix

Survey questions

Which of the following best describes your current workplace?

What is your career level?

What is (are) your physics topic(s) of interest?

Which sector(s) is (are) relevant to your work, studies, or research?

Does your role involve the use of AI?

Do you collaborate, or have you been collaborating with any of the following on AI-related projects?

If you use AI in your role and/or elsewhere, what types of tasks do you use it for?

How would you identify your level of experience with different AI topics?

Do you think that AI offers potential benefits to physics research and innovation in the UK and Ireland? Where do you think AI might offer greatest potential benefit in physics research and innovation?

Do you think that the use of AI carries any concerns to physics research and innovation in the UK and Ireland? Which are your potential greatest concerns regarding AI in physics research and innovation?

What areas do you see as important to make the most of AI for physics and innovation and would like the IOP to advocate for?

Where are you based?

Are you an IOP member?

Which of the following options best describes your gender?

Your age: Please tick the box corresponding to your age group

Free text comments

What areas do you see as important to make the most of AI for physics and innovation and would like the IOP to advocate for?

Responses were clustered in three categories:

Regulation and standards

“The MOST important thing the IOP could do is to push back against AI hype and really actually get the government to take a hard look at the ethics and morality of AI, particularly generative AI. It cannot be just another thing that we accept as a society is bad but becomes so engrained that we all just must shrug and go along with it."

"Standards for the application and usage and rigorous continuous inspection is need to be carried out and all these can be led by Institutions such as IOP, so that the general public are more aware and are assisted /served and not disregarded-pushed aside in its favour through economic ease of usage. Greater regulations must be put in place across all fields so that General public are aware and assured that standards are met, particularly where Health/Welfare are concerned."

"AI regulation will be very important, particularly in verification of approach and results. However, putting in regulations too early can stifle innovation and lead to solution spaces which are not optimal; and which might not be economically viable. Important not to develop a new nanny state."

"We need regulation on the construction of training set!"

"Standardised processes for the implementation and use of AI tools."

"Regulation needs to happen, both around the use of copyrighted information and works, but also about the safeguards that need to be in place."

"Remove all regulations. I strongly believe that the less rules / paperwork there is to hold this remarkably useful ai technology back, the faster progress will be made."

"Please do advocate for maintaining high standards in published articles and research labs/projects."

"Regulation! We need to be led by competent and flexible regulation."

"Ethical and regulatory controls"

Training

"Training to understand when the results can be relied upon, and losing this trend of using a magic black box without careful interpretation and judgement"

"Education about what it can and CANNOT do. The importance of understanding things BEFORE applying AI to a problem"

"Access to guidance on best practice, this is more than just skills development"

"Greater public understanding of what AI is and does, its benefits and its limitations."

"Conferences, discussion forums, support of the chartered data scientist qualification being set up by the association of data scientists within IOP."

"A lot of education is needed for users to understand what the limitations are of AI."

“Promote critical examination of AI methods (via meetings, seminars), and promote more transparency, particularly wrt 'training'”

“Code of practice needs to be developed, and the current speed of technology development is overtaking the community's ability to understand the implications of AI use, understand suitable mitigation strategies (NB this is not the same as understanding "how it works"), and reach consensus about best practice”

“Develop a code of best practice”

“Broad general education on the uses and limitations of AI so that those not directly involved in its use have realistic expectations of what it can achieve. Training of people using AI so that they fully understand what it actually does and its limits and the ability to recognise when they are being confronted by Artificial Stupidity or Artificial bias. Possibly tiered qualification scheme from school level upwards.”

Environment

“Environmentally responsible use of AI given the energy requirements, and awareness of the ethics of how models are trained and the rights to training data.”

“I would like to see the IOP to push for research into low power AI. The human brain only requires 10-20 watts of power, whilst the current approach to AI needs megawatts of power. Lower power AI would potentially also address equitability issues.”

“Considered planning for the location of AI computing resource, so that its environmental harm can be offset by district heating and skilled jobs in poor economies”

“We could use AI servers to provide district heating in the colder and less affluent areas of Britain. Increased work for computer scientists would boost those local economies too. We should be introducing this idea into town and city planning, as it would be a win-win solution to the problem of AI computing's excessive power requirements. IOP would be a strong and credible voice to put this forward as a sensible proposal.”

“Wider recognition of the environmental / energy impact.”

“IOP should advocate for measured use where it will have the greatest use.”

Which are your potential greatest concerns regarding AI in physics research and innovation?

Responses were clustered in three categories:

How we do research

“Completely misses and corrupts the central aims and values of education and research”

“Concerns it will replace physical models and associated loss of understanding of output”

“Loss of physics understanding of phenomena”

“Potential risk of reducing sensitivity to unknown processes/undiscovered things by training on models of the known”

“My main concern is the "gratuitous" use of AI in everything, especially in research where it appears trendy or cool, but a physical model would probably be more appropriate and more insightful. There is the useful fear when something transitions from niche to mainstream (where something changes from a technique to tool) that people will use it because it is easy to use, without understanding how it works and appreciating the ethical/IP/commercial/technical impacts of what they are doing.”

“In an analysis, there is concern about how well each step in the process is understood. While a black box can be fine as a step, it needs to be understood, not just used quickly.”

“I have strong reservations - while there is much potential benefit, we also lose a lot - in certainty and repeatability of results for starters, without which we don't have 'science' anymore”

Loss of critical thinking/physics understanding

“Over-reliance on AI risks losing expertise and the ability to train the next generation of physicists on the basic functions that have been replaced by AI. It is impossible to critique the work of an AI in summarising a research paper, for example, if you have never summarised a paper yourself.”

“Loss of basic understanding of physics models and too great a reliance on AI to build models rather than thinking about things from first principles. End up with a generation of 'physicists' who don't know how to do real physics.”

“I see young people who use instruments without any understanding of the underlying principles, as interfaces have become more "black-box". AI applied to intellectual tasks risks the same.”

“We may be in danger of publishing research we don't fully understand ourselves. We may even lose basic research skills due to lack of use. Like mental arithmetic has definitely suffered after the advent of calculators, spelling has definitely suffered after the advent of predictive text. The film 'Idiocracy' springs to mind.”

“A proper understanding of previous research must be gained by reading articles and working with people. Having AI generate summaries might be useful, but it will be tempting to rely on them too much, and not to spend the much larger time understanding things properly.”

“Can undermine student learning”

“AI becoming a crutch that scientists rely on instead of using their brains.”

Environment

“We are told AI and sustainability are key priorities but ignore the environment cost of large datacentres. I am worried by practices in the IT industry will affect the nuclear industry as they are now massively investing in this area to feed electricity to their AI models.”

“Environmental impacts (e.g. Drax is building new CC&S power stations in the USA specifically to deal with data center demand. Carbon capture is known to be a sub-optimal solution to our climate crises and distracts from useful developments in large-scale energy storage)”

“Also the massive environmental impact should not be overlooked. Just this last week Microsoft have announced that they are recommissioning the 3 Mile Island nuclear facilitate to power a new AI data centre. and research has also shown that producing 100 words from Chat GPT consumes 3 litres of water. The slavish unfettered quest for AI has serious consequences in so many areas of society and for our planet.”

“I am also very concerned about the energy and water consumption of data centres, AI may undermine any progress made towards the reduction of carbon emissions.”

“Additionally, I would be highly concerned about the power usage. We physicists are very well placed to understand our precise impact on the environment, and we have a responsibility to minimise it. We therefore should avoid using more power-hungry technologies save where we are certain the benefit significantly outweighs the costs.”

Other comments

“I am also concerned about whether the use of AI will create another "dark age", in that the only way AI can work is the information is already available on the internet somewhere. On topics I know much about I find AI to be very ignorant ...largely because a huge amount of industrial/engineering knowledge is not searchable. We could easily find that much knowledge from before the start of the internet gets lost, and would need rediscovering.”

“The problem I foresee is a subtle one. If we start using AI to generate content - by that I mean going beyond text improvements of one's own writing - then scientific papers and other documents will get longer, more boring, and there will be more of them. The significant content will be lost in the noise. When a human writes a paper on physics research (or any other topic) the mind is automatically focussed on the significant facts. Authors miss stuff out, they might not cite other relevant work, but peer review picks up on the more important omissions, and most readers are capable of filling the gaps after that (and it is a good intellectual challenge to do so). I would far rather read a 6 page article with gaps than a thorough 30 page article. By over creation, we will make the reading of literature a form of suffocation, destroy researchers' self-belief, and cease to be innovative in our research."

Workshop

The workshop participants had varied backgrounds but due to the small overall numbers, not all areas of physics and industry sectors were covered.

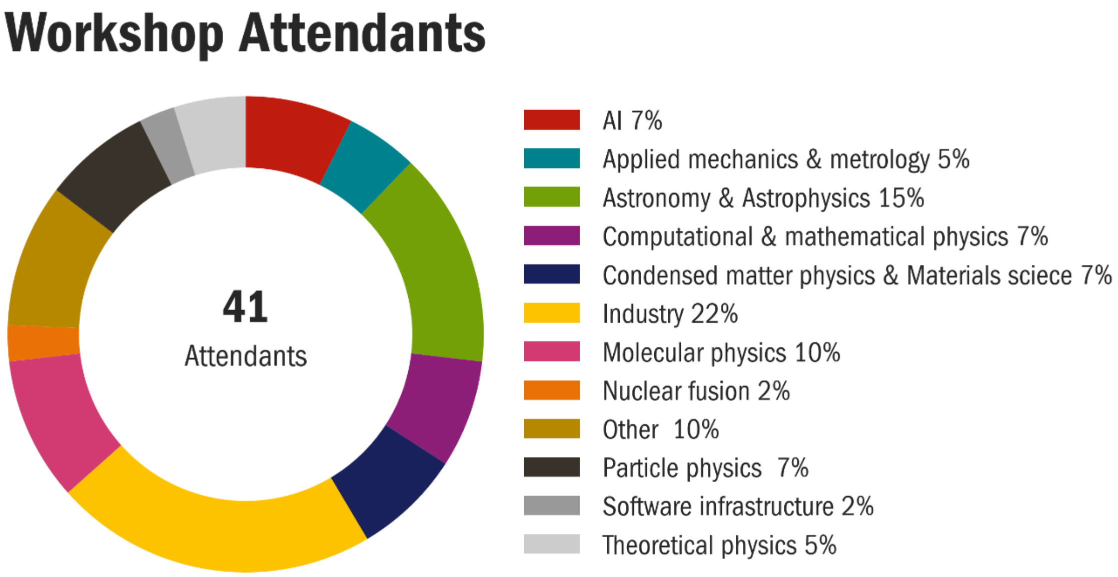

Figure 15 Backgrounds of the workshop participants.

Summary Linkages from Items on the Landscape which Received Workshop Votes

Trends and Drivers

Innovation Opportunities	TD01 Increasing need to learn from and process large and complex data	TD03 Simulation of complex physical processes / surrogate models	TD04 More efficient/low power computing technology - neuromorphic computing	TD05 Trend to build symmetries and physics into AI models	TD06 Accelerated chemistry and material science workflows, HPC, DFT methods	TD07 New algorithmic advancements and learning paradigms such as neural operators	TD08 Renewed focus on safety and trust ethics	TD09 Ethics regulation needs to catch up with AI developments	TD10 Opportunities for improving automation and productivity	TD11 In silico modelling of drug design and complex/rare diseases	TD12 Need for education, awareness and understanding of AI	TD13 Computing paradigms will evolve to be more efficient	TD14 Multimodal personalised medicine is growing	TD15 Need to optimise energy provision and manage increasing grid complexity	TD16 Opportunities for faster and more efficient drug design / discovery	TD17 SDGs and climate crisis need effective computational solutions	TD18 Combine data from multiple sources for better predictive maintenance / fault detection	TD19 Optimization and decision making strategies in manufacturing	TD20 Need for faster weather / climate forecasting for different sectors	
Physics-informed AI	3	2	1	5	4	4	2			2					2				2	10
Explainable and interpretable AI at different resolutions							1				1									2
Challenge: ensuring generator to training data is reliable	1	2			1		1	1		1	1				2					8
Develop UQ methods using AI NN technology		1					1													2
Transfer existing Multimodal AI models to physics	1	1																		2
Bayesian optimization / experimental design		1							1					1				1		4
Harnessing AI to enable creative focus on science	2	2	2	2	2	2	2	2	4	2	3	2	2	2	2	2	2	2	2	19
Neural network representation of large datasets	2	1																		2
Learning from equations - e.g. using neural networks as optimizers	2	1		1		4				1		1								6
Multifidelity learning - high & low quality data processing	3	3			4		1		1	1								1	1	8
General purpose platform for AI simulation	1	2		1															2	4
Feature explanation techniques	2						1													2
Agentic AI	1	1					1		2											4
Smaller scale application specific AI	1		1						1											3
Causal models	1		1			1	2			1				1						6
Machine learning of interatomic potentials		3		2	2				1	3										5
Reduced order modelling	1	3	1	2						1										5
	13	13	5	6	5	4	9	2	6	8	3	2	1	3	3	1	1	3	4	

Physics Research Enablers

Innovation Opportunities		PR01 Incentivising industry academia collaboration	PR02 Skills development and education in AI for physics	PR03 Interdisciplinary research funding and incentives	PR04 Data infrastructure storage, access, and sharing standards	PR05 Appropriate regulatory framework.	PR06 Physics AI community	PR07 Varied and comprehensive computational resources	PR08 IOP to facilitate access to good practice framework for AI application	PR09 Incentivising sustainable software development and sharing	PR10 Innovation spaces and regulatory sandpits	PR11 Guidelines and platform for industry-academic collaboration.	PR12 More accessible overseas talent visa	PR13 Early stage education on AI	PR14 Accreditation /certification around application of AI
Physics-informed AI	12	1	7	4		1	1	4	1	2		1	1	1	1
Explainable and interpretable AI at different resolutions															
Challenge: ensuring generator to training data is reliable	13	1	5	3	4	1		4	1	2	1	1	1	1	1
Develop UQ methods using AI NN technology	12	1	5	3	1	1		4	1	2		1	1	1	1
Transfer existing Multimodal AI models to physics	12	1	5	4	2	1		3	1	2		1	1	1	1
Bayesian optimization / experimental design	11	1	4	3		1		3	1	2		1	1	1	2
Harnessing AI to enable creative focus on science	12	1	5	4		1	1	4	1	2		1	1	1	1
Neural network representation of large datasets	12	1	6	3		1		4	1	2	1	1	1	1	1
Learning from equations - e.g. using neural networks as optimizers	11	1	4	3		1		4	1	2		1	1	1	1
Multifidelity learning - high & low quality data processing	11	1	5	3		1		3	1	2		1	1	1	1
General purpose platform for AI simulation	12	1	4	3	2	1		4	1	2		1	1	1	2
Feature explanation techniques	11	1	5	3		1		3	1	2		1	1	1	1
Agentic AI	13	1	4	4	1	1	1	3	1	2		1	1	1	1
Smaller scale application specific AI	11	1	4	4		1		3	1	2		1	1	1	1
Causal models	11	1	5	3		1		3	1	2		1	1	1	1
Machine learning of interatomic potentials	12	1	4	3	1	1		3	1	2		1	1	1	1
Reduced order modelling	11	1	4	3		1		3	1	2		1	1	1	1
		16	16	16	6	16	3	16	16	16	2	16	16	16	16

IOP Institute of Physics

IOP Institute of Physics	Physics and AI Landscape 19 November 2024		Short-term 1 year	Medium-term 2 years	Long-term 5 years	Vision
Trends and Drivers	Macrotrends	Sociological trends	Need for education, awareness and understanding of AI			
		Technological trends		New algorithmic advancements and learning paradigms such as neural operators	More efficient/low power computing technology - neuromorphic computing	Computing paradigms will evolve to be more efficient
		Environmental trends	SDGs and climate crisis need effective computational solutions			
		Ethical trends		Renewed focus on safety and trust ethics		
			Ethics regulation needs to catch up with AI developments			
	Industry trends & needs	Energy	Need to optimise energy provision and manage increasing grid complexity			
		Manufacturing		Optimization and decision making strategies in manufacturing		
		Medical & pharma	In silico modelling of drug design and complex/rare diseases			
				Multimodal personalised medicine is growing		
			Opportunities for faster and more efficient drug design / discovery			
		Other / all industry		Opportunities for improving automation and productivity		
			Combine data from multiple sources for better predictive maintenance / fault detection			
			Need for faster weather / climate forecasting for different sectors			
	Physics	Physics trends and needs	Increasing need to learn from and process large and complex data			
			Simulation of complex physical processes / surrogate models			
				Trend to build symmetries and physics into AI models		
				Accelerated chemistry and material science workflows, HPC, DFT methods		
Innovation Opportunities	Value capture opportunities	Data analysis	Develop UQ methods using AI NN technology			
			Learning from equations - e.g. using neural networks as optimizers			
			Feature explanation techniques			
		Predictive analytics & forecasting	Machine learning of interatomic potentials			
		Simulation	Transfer existing Multimodal AI models to physics			
			Neural network representation of large datasets			
			General purpose platform for AI simulation			
			Causal models			
			Reduced order modelling			
		Task automation	Bayesian optimization / experimental design			
			Harnessing AI to enable creative focus on science			
		Other opportunities	Physics-informed AI		Explainable and interpretable AI at different resolutions	
			Multifidelity learning - high & low quality data processing			
			Agentic AI			
			Smaller scale application specific AI			
		Challenges & concerns		Challenge: ensuring generator to training data is reliable		
Physics Research Enablers	Enablers	Policy	Appropriate regulatory framework.			
			Incentivising sustainable software development and sharing			
				Guidelines and platform for industry-academic collaboration.		
		Standards	Data infrastructure storage, access, and sharing standards			
		Skills & Education	Skills development and education in AI for physics			
			More accessible overseas talent visa.	Early stage education on AI		
				Accreditation /certification around application of AI		
		Infrastructure	Varied and comprehensive computational resources			
			Innovation spaces and regulatory sandpits			
		Finance / investment	Interdisciplinary research funding and incentives			
		Relationships / collaborations	Physics AI community			
		Activities	IOP to facilitate access to good practice framework for AI application			
		Other enablers	Incentivising industry academia collaboration			

ID	Trends and Drivers	Physics-informed AI	Explainable and interpretable AI at different resolutions	Challenge: ensuring generator to training data is reliable	Develop UQ methods using AI NN technology	Transfer existing Multimodal AI models to physics	Bayesian optimization / experimental design	Harnessing AI to enable creative focus on science	Neural network representation of large datasets	Learning from equations - e.g. using neural networks as optimizers	Multifidelity learning - high & low quality data processing	General purpose platform for AI simulation	Feature explanation techniques	Agentic AI	Smaller scale application specific AI	Causal models	Machine learning of interatomic potentials	Reduced order modelling	TOTAL
TD01	Increasing need to learn from and process large and complex data																		13
TD03	Simulation of complex physical processes / surrogate models																		13
TD04	More efficient/low power computing technology - neuromorphic computing																		5
TD05	Trend to build symmetries and physics into AI models																		6
TD06	Accelerated chemistry and material science workflows, HPC, DFT methods																		5
TD07	New algorithmic advancements and learning paradigms such as neural																		4
TD08	Renewed focus on safety and trust ethics																		9
TD09	Ethics regulation needs to catch up with AI developments																		2
TD10	Opportunities for improving automation and productivity																		6
TD11	In silico modelling of drug design and complex/rare diseases																		8
TD12	Need for education, awareness and understanding of AI																		3
TD13	Computing paradigms will evolve to be more efficient																		2
TD14	Multimodal personalised medicine is growing																		1
TD15	Need to optimise energy provision and manage increasing grid complexity																		3
TD16	Opportunities for faster and more efficient drug design / discovery																		3
TD17	SDGs and climate crisis need effective computational solutions																		1
TD18	Combine data from multiple sources for better predictive maintenance / fault																		1
TD19	Optimization and decision making strategies in manufacturing																		3
TD20	Need for faster weather / climate forecasting for different sectors																		4

ID	Physics Research Enablers	Physics-informed AI	Explainable and interpretable AI at different resolutions	Challenge: ensuring generator to training data is reliable	Develop UQ methods using AI NN technology	Transfer existing Multimodal AI models to physics	Bayesian optimization / experimental design	Harnessing AI to enable creative focus on science	Neural network representation of large datasets	Learning from equations - e.g. using neural networks as optimizers	Multifidelity learning - high & low quality data processing	General purpose platform for AI simulation	Feature explanation techniques	Agentic AI	Smaller scale application specific AI	Causal models	Machine learning of interatomic potentials	Reduced order modelling	TOTAL
PR01	Incentivising industry academia collaboration																		16
PR02	Skills development and education in AI for physics																		16
PR03	Interdisciplinary research funding and incentives																		16
PR04	Data infrastructure storage, access, and sharing standards																		6
PR05	Appropriate regulatory framework.																		16
PR06	Physics AI community																		3
PR07	Varied and comprehensive computational resources																		16
PR08	IOP to facilitate access to good practice framework for AI application																		16
PR09	Incentivising sustainable software development and sharing																		16
PR10	Innovation spaces and regulatory sandpits																		2
PR11	Guidelines and platform for industry-academic collaboration.																		16
PR12	More accessible overseas talent visa.																		16
PR13	Early stage education on AI																		16
PR14	Accreditation /certification around application of AI																		16

Macro Impacts										
Societal			■				■		■	■
Scientific	■	■	■	■	■	■	■		■	■
Economic		■	■	■	■	■	■	■	■	■
Environmental			■					■	■	■
Physics Disciplines	Physics-informed AI (IN01)	Reliability and traceability of datasets (IN02)	Tracking uncertainty from the data to the model's prediction (IN03)	Experimental design (IN05)	Harnessing AI to enable creative focus on science (IN06)	Multifidelity (IN10)	General purpose platform for AI simulation (IN11)	Quantum accurate all-atom force fields for realistic chemistry & materials problems (IN16)	Complexity Science	Communicating the value of AI and Agreeing, communicating and incorporating the values of AI
Astro, nuclear & particle physics	■	■	■	■	■	■	■			■
Atomic, molecular & optical physics	■	■	■	■	■	■	■	■		■
Biophysics, soft matter & fluids	■	■	■	■	■	■	■	■	■	■
Condensed matter, materials & nanotech	■	■		■	■	■	■	■	■	■
Environmental and geophysics	■	■		■	■		■	■	■	■
Mathematical & computational physics	■	■	■	■	■		■	■	■	■
Photonics & quantum technologies	■	■		■	■		■	■		■
IOP / Other Physics	■		■	■	■		■	■	■	■
Industry Sectors										
Aerospace, defence & space	■	■	■	■	■		■	■	■	■
Agriculture & food		■					■	■		■
Construction		■					■			■
Energy	■	■	■	■	■		■	■	■	■
Financial services		■					■		■	■
Information Technology		■			■	■	■			■
Manufacturing		■		■	■		■	■		■
Medical & pharma	■	■	■		■		■	■		■
Retail		■					■		■	■
Other industry							■	■	■	■

Figure 16 Summary of Potential Impacts of Proposals to Progress.

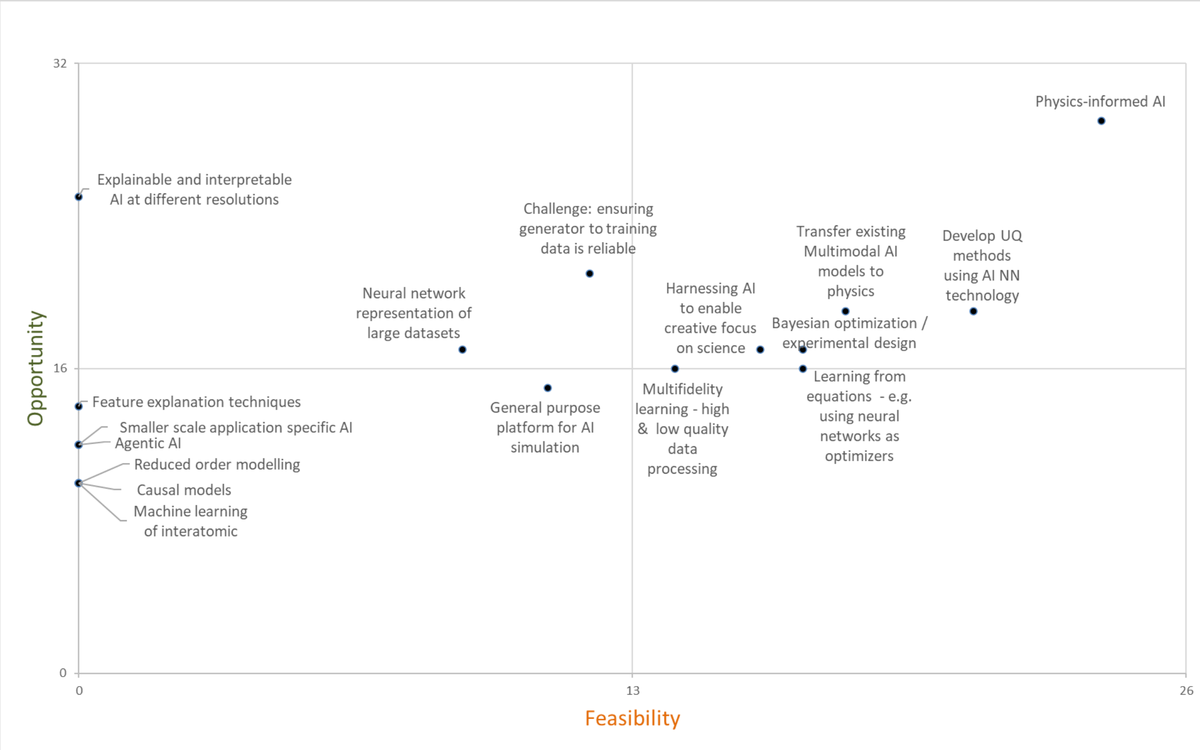

Figure 17 Priority Innovation Opportunities: Opportunity-Feasibility Matrix.

Workforce

In the UK, about 22% of physics and astronomy first degree graduates graduating in 2019 and in the workforce in 2020/21 were working in Information and Communication industries compared to with 6% of all equivalent graduates from first degrees, 6% of chemistry graduates, 4% of biosciences graduates, and 15% of maths graduates (Source). While it is hard to quantify how many of these graduates are working in AI specifically, 6% of the AI early-career workforce comes from a higher education STEM background in physical sciences (Source).

In the US, 13% of PhD graduates were hired in data science jobs and 14% in computer software (Source, 2016-2020); the numbers for 2020-2022 were 21% and 11%, respectively. These figures do not reflect the exact numbers of physicists working in AI specifically, but there is abundant anecdotal evidence that physics contributes to the AI workforce[51,52].

[51] https://usparticlephysics.org/brochure/particle-physicists-advance-artificial-intelligence/
[52] https://www.symmetrymagazine.org/article/from-physics-to-data-science