TEJAS Journal of Technologies and Humanitarian Science
ISSN-2583-5599
Vol.05, I.01 (2026)
https://www.tejasjournals.com/
https://doi.org/10.63920/ICFCSAI2025.003

The Role of AI in Democratizing Laser Physics Research and Education

Dr. Rekha Sharma[a] , Dr. Shalini Sharma[b] ,Mr. S. Pushpendra[c] , Dr. K. Sunil[d]

[a,b,c,d] Assistant Professor, Institute of Engineering & Technology, Dr. B.R. Ambedkar University, Agra

[a]sharmarswarup@rediffmail.com, [b]ietshalini@gmail.com, [c]pushpendra.skb@gmail.com, [d]k.sunil.ibs@gmail.com

KEYWORDS

Low-light image enhancement, deep neural networks, comprehensive overview, Object Detection models, constructive discussions and prospects.

ABSTRACT

Laser physics has traditionally required substantial financial resources and specialized equipment, limiting meaningful research participation to well-funded institutions. This study examines how artificial intelligence is transforming access to laser physics through computational experimentation, virtual laboratories, and automated data analysis. Through literature review and case study analysis, we demonstrate that AI-powered simulation environments and machine learning tools are enabling researchers worldwide to contribute to laser physics regardless of institutional resources. Virtual reality laboratories provide experimental experiences without expensive equipment, while AI-assisted analysis tools democratize sophisticated data processing capabilities. However, challenges remain regarding the digital divide, data quality assurance, and maintaining experimental skills alongside computational approaches. Our findings suggest that AI presents unprecedented opportunities for inclusive scientific advancement in laser physics, though careful implementation is essential to preserve research rigor while expanding access.

1. INTRODUCTION

Laser physics research has long been characterized by significant barriers to entry, requiring expensive specialized equipment and substantial institutional support [1]. Traditional laser research demands femtosecond laser systems costing hundreds of thousands of dollars, ultra-high vacuum chambers, and sophisticated detection equipment that place meaningful contributions beyond reach of many institutions [2]. This resource inequality has concentrated laser physics research in well-funded universities and national laboratories, potentially limiting diversity of perspectives and innovative approaches.

The emergence of artificial intelligence presents an unprecedented opportunity to democratize laser physics [3]. AI tools enable new forms of computational experimentation, data analysis, and virtual laboratory experiences that can substitute for or complement traditional experimental approaches [4]. This paper investigates AI's transformative potential in making laser physics more accessible, examining both opportunities and challenges

Corresponding Author: Dr. Rekha Sharma, Assistant Professor, Institute of Engineering & Technology, Dr. B.R. Ambedkar University, Agra.
Email: sharmarswarup@rediffmail.com

TEJAS Journal of Technologies and Humanitarian Science
ISSN-2583-5599
Vol.05, I.01 (2026)
https://www.tejasjournals.com/
https://doi.org/10.63920/ICFCSAI2025.003

2. BACKGROUND

Laser physics research has historically required substantial capital investment and technical infrastructure. Equipment investments typically range from $500,000 to several million dollars, including femtosecond laser systems, optical tables, and precision measurement instruments [5]. Beyond costs, laser research demands specialized facilities with vibration isolation, temperature control, and clean room environments [6].

Technical expertise presents another significant barrier. Laser physics requires years of specialized training in optics, quantum mechanics, and advanced experimental techniques [7]. Graduate students often spend 1-2 years learning to operate complex laser systems before contributing to original research [8].

Artificial intelligence has increasingly been applied across scientific disciplines, with notable impacts in physics [9]. Machine learning algorithms demonstrate success in pattern recognition, data analysis, and prediction tasks previously intractable [10]. In photonics specifically, AI applications have emerged in optical design optimization, laser parameter control, and spectroscopic data analysis [11].

Cloud-based machine learning platforms, open-source software libraries, and pre-trained models have lowered technical barriers to implementing AI solutions [12]. This democratization creates opportunities for application in traditionally resource-intensive fields like laser physics.

3. METHODOLOGY

This study employed a mixed-methods approach combining literature review, case study analysis and expert consultation to assess AI's current state and future potential in democratizing laser physics.

A comprehensive literature review was conducted using Web of Science, IEEE Xplore, and arXiv databases. Search terms included combinations of "artificial intelligence," "machine learning," "laser physics," "photonics," and "democratization." Publications from 2018-2024 were prioritized to capture recent developments.

Representative case studies were selected illustrating different aspects of AI's democratizing impact: AI-powered laser optimization platforms, virtual laboratories, machine learning spectroscopic tools, and online educational platforms. Semi-structured interviews were conducted with laser physics researchers, educators, and AI specialists from both well-resourced and resource-constrained institutions

4. RESULTS AND DISCUSSION

Computational Research Democratization - AI has enabled significant democratization through computational approaches reducing dependence on expensive physical equipment. Machine learning models trained on existing experimental data can predict laser behavior, optimize parameters, and suggest experimental conditions without requiring actual laser systems [13]. Neural network models predict output characteristics of various laser configurations based on input parameters, allowing computational exploration before expensive experimental validation [14].

Cloud-based AI platforms provide sophisticated computational resources accessible regardless of institutional computing infrastructure. Platforms like Google Colab offer free GPU-accelerated computing suitable for machine learning applications in laser physics [15]. This enables researchers at under-resourced institutions to perform computationally intensive analyses previously available only to well-funded laboratories.

Open-source AI tools specifically for photonics research have further lowered barriers. Libraries incorporating machine learning capabilities allow researchers to leverage AI techniques without deep machine learning expertise [16].

Educational Transformation - AI has transformed laser physics education through personalized learning experiences and virtual laboratory access. Intelligent tutoring systems adapt to individual learning styles, providing customized explanations of complex concepts [17]. These systems identify common misconceptions and provide targeted interventions.

TEJAS Journal of Technologies and Humanitarian Science
ISSN-2583-5599
Vol.05, I.01 (2026)
https://www.tejasjournals.com/
https://doi.org/10.63920/ICFCSAI2025.003

Virtual and augmented reality environments powered by AI create immersive laboratories simulating real experimental conditions [18]. Students manipulate virtual laser systems, observe nonlinear optical phenomena, and conduct experiments impossible or dangerous in physical laboratories. AI-generated problem sets provide unlimited practice opportunities tailored to individual needs [19].

Enhanced Data Analysis - Machine learning algorithms have dramatically improved data analysis efficiency in laser physics. Automated feature extraction and pattern recognition identify subtle signals in spectroscopic data that traditional methods might miss [20]. This proves particularly valuable for time-resolved spectroscopy experiments generating large, complex datasets.

AI-assisted literature review tools help researchers navigate rapidly growing research bodies. Natural language processing algorithms summarize key findings, identify trends, and suggest relevant papers based on research interests [21]. Automated experimental design suggestions based on machine learning analysis of successful previous experiments guide research directions and optimize resource allocation [22].

Global Collaboration - AI-powered translation and communication tools have reduced language barriers in international collaboration [23]. Real-time translation of technical documents and automated research paper summarization facilitate knowledge sharing across linguistic boundaries. Standardized AI protocols enable collaborative research projects spanning multiple institutions and countries [24].

Challenges and Limitations - Several challenges limit AI's democratizing potential. The digital divide affects access to high-speed internet and modern computing devices necessary for AI applications [25]. Rural and economically disadvantaged institutions may still face barriers to cloud-based AI resources.

Quality and reliability concerns present another challenge. Machine learning models depend on training data quality, and biases in historical research data can be perpetuated or amplified [26]. Over-reliance on computational approaches at the expense of experimental skills and physical intuition poses particular concerns in experimental physics.

Data privacy and security issues arise when processing sensitive research data using cloud-based platforms [27]. Intellectual property concerns may limit willingness to share data and models, potentially reducing collaborative benefits.

5. IMPLICATIONS AND FUTURE DIRECTIONS

The democratization of laser physics through AI presents both opportunities and responsibilities. Educational institutions must adapt curricula to balance traditional experimental skills with computational approaches, ensuring students develop both physical intuition and AI literacy [28]. Funding agencies should consider supporting AI infrastructure and training for equitable access.

Future AI developments promise enhanced accessibility. Advances in automated experiment planning and robotic laboratory systems may enable remote access to physical laser systems, combining computational and experimental benefits [29]. Integration with emerging technologies like quantum computing may open entirely new research directions that are inherently computational rather than equipment-dependent [30].

6. CONCLUSION

Artificial intelligence is fundamentally transforming laser physics by lowering traditional barriers and creating new participation pathways. Through computational experimentation, AI-enhanced learning platforms, and improved data analysis capabilities, AI enables worldwide contributions regardless of institutional resources. Virtual laboratories provide experimental experiences without expensive equipment, while machine learning tools democratize sophisticated analysis capabilities.

However, successful democratization requires addressing challenges including the digital divide, data quality assurance, and balancing computational with experimental skills. The future will likely feature hybrid approaches combining AI-enabled computational capabilities with traditional experimental methods. Thoughtful

TEJAS Journal of Technologies and Humanitarian Science
ISSN-2583-5599
Vol.05, I.01 (2026)
https://www.tejasjournals.com/
https://doi.org/10.63920/ICFCSAI2025.003

implementation that preserves laser physics research rigor while leveraging AI's accessibility-enhancing capabilities will determine success in creating a more inclusive and innovative research environment.

5.REFERENCES

[1]. Silfvast, W. T. (2004). Laser Fundamentals. Cambridge University Press.

[2]. Rullière, C. (Ed.). (2005). Femtosecond Laser Pulses: Principles and Experiments. Springer Science & Business Media.

[3]. Butler, K. T., Davies, D. W., Cartwright, H., Isayev, O., & Walsh, A. (2018). Machine learning for molecular and materials science. Nature, 559(7715), 547-555.

[4]. Carleo, G., Cirac, I., Cranmer, K., Daudet, L., Schuld, M., Tishby, N., ... & Zdeborová, L. (2019). Machine learning and the physical sciences. Reviews of Modern Physics, 91(4), 045002.

[5]. Manzoni, C., & Cerullo, G. (2016). Design criteria for ultrafast optical parametric amplifiers. Journal of Optics, 18(10), 103501.

[6]. Paschotta, R. (2021). Field Guide to Laser Pulse Generation. SPIE Press.

[7]. Hecht, J. (2018). Understanding Lasers: An Entry-Level Guide. John Wiley & Sons.

[8]. Trebino, R. (2012). Frequency-Resolved Optical Gating: The Measurement of Ultrashort Laser Pulses. Springer Science & Business Media.

[9]. Schmidt, J., Marques, M. R., Botti, S., & Marques, M. A. (2019). Recent advances and applications of machine learning in solid-state materials science. npj Computational Materials, 5(1), 1-36.

[10]. LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. Nature, 521(7553), 436-444.

[11]. Miscuglio, M., & Sorger, V. J. (2020). Photonic tensor cores for machine learning. Applied Physics Reviews, 7(3), 031404.

[12]. Chen, T., & Guestrin, C. (2016). XGBoost: A scalable tree boosting system. Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, 785-794.

[13]. Baumeister, T., Brunton, S. L., & Kutz, J. N. (2018). Deep learning and model predictive control for self-tuning mode-locked lasers. Journal of the Optical Society of America B, 35(3), 617-626.

[14]. Genty, G., Salmela, L., Dudley, J. M., Brunner, D., Kokhanovskiy, A., Kobtsev, S., & Turitsyn, S. K. (2021). Machine learning and applications in ultrafast photonics. Nature Photonics, 15(2), 91-101.

[15]. Bisong, E. (2019). Building machine learning and deep learning models on Google cloud platform. In Building Machine Learning and Deep Learning Models on Google Cloud Platform (pp. 59-64). Apress.

[16]. Shen, Y., Harris, N. C., Skirlo, S., Prabhu, M., Baehr-Jones, T., Hochberg, M., ... & Soljačić, M. (2017). Deep learning with coherent nanophotonic circuits. Nature Photonics, 11(7), 441-446.

[17]. Kulik, J. A. (2016). Learning and logo. In Handbook of Research on Educational Communications and Technology(pp. 61-74).

[18]. Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. Education and Information Technologies, 23(4), 1515-1529.

TEJAS Journal of Technologies and Humanitarian Science
ISSN-2583-5599
Vol.05, I.01 (2026)
https://www.tejasjournals.com/
https://doi.org/10.63920/ICFCSAI2025.003

[19]. Graesser, A. C., Conley, M. W., & Olney, A. (2012). Intelligent tutoring systems. In APA Educational Psychology Handbook (Vol. 3, pp. 451-473).

[20]. Raccuglia, P., Elbert, K. C., Adler, P. D., Falk, C., Wenny, M. B., Mollo, A., ... & Norquist, A. J. (2016). Machine-learning-assisted materials discovery using failed experiments. Nature, 533(7601), 73-76.

[21]. Westergaard, D., Stærfeldt, H. H., Tønsberg, C., Jensen, L. J., & Brunak, S. (2018). A comprehensive and quantitative comparison of text-mining in 15 million full-text scientific articles. PLoS Computational Biology, 14(2), e1005962.

[22]. Griffiths, R. R., & Hernández-Lobato, J. M. (2020). Constrained Bayesian optimization for automatic chemical design using variational autoencoders. Chemical Science, 11(2), 577-586.

[23]. Koehn, P. (2020). Neural Machine Translation. Cambridge University Press.

[24]. Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., ... & Mons, B. (2016). The FAIR Guiding Principles for scientific data management and stewardship. Scientific Data, 3(1), 1-9.

[25]. Dijk, J. V. (2020). The Digital Divide. John Wiley & Sons.

[26]. Barocas, S., Hardt, M., & Narayanan, A. (2019). Fairness and Machine Learning. MIT Press.

[27]. Veale, M., Binns, R., & Edwards, L. (2018). Algorithms that remember: model inversion attacks and data protection law. Philosophical Transactions of the Royal Society A, 376(2133), 20180083.

[28]. National Academy of Sciences. (2018). Graduate STEM Education for the 21st Century. National Academies Press.

[29]. Segler, M. H., Preuss, M., & Waller, M. P. (2018). Planning chemical syntheses with deep neural networks and symbolic AI. Nature, 555(7698), 604-610.

[30]. Preskill, J. (2018). Quantum computing in the NISQ era and beyond. Quantum, 2, 79.