

PUBLICATION IN SEVERAL STEPS

Mila Ilieva-Obretenova, Maya Tomova

University of Mining and Geology “St. Ivan Rilski”, 1700 Sofia; E-mail: mila.ilieva@mgu.bg; maya.tomova@mgu.bg

ABSTRACT. The article provides a comprehensive review of the application of artificial intelligence in university education and research. Both students and researchers advocate for reform, emphasising the need for broader integration of Artificial Intelligence into curricula. This transformation, however, presents significant challenges for educators, who must equip students with the ability to formulate precise questions and critically evaluate AI-generated responses. To illustrate this process, the authors assign a task to Copilot: exploring how AI can support the writing of a scientific paper on the topic *Extreme temperatures and their impact on mineral resources in Europe*. Subsequently, the research questions are refined to guide the investigation and the composition of the article. The discussion further outlines directions for the development of academic skills in the era of AI, highlighting the importance of fostering critical thinking and methodological rigor. In conclusion, the article asserts that AI will inevitably become an integral component of both scientific inquiry and higher education, provided that its use is governed by strict ethical frameworks.

Key words: artificial intelligence (AI), university education, AI-generated responses, mineral resources, academic skills.

ПУБЛИКАЦИЯ В НЯКОЛКО СЪПКИ

Мила Илиева-Обретенкова, Мая Томова

Минно-геоложки университет „Св. Иван Рилски“, 1700 София

РЕЗЮМЕ. Статията представя подробен преглед на приложението на изкуствения интелект в университетското образование и изследванията. Студентите и изследователите са застъпници на реформа, акцентирайки върху необходимостта от по-широка интеграция на изкуствения интелект в хорариума. Трансформацията, обаче, поставя значителни предизвикателства пред преподавателите, които трябва да развият у студентите способността да формулират прецизни въпроси и критично да оценяват генерираните от изкуствен интелект отговори. За да се илюстрира този процес, авторите възлагат на Copilot задача: да изследва как ИИ може да подпомага писането на научна статия по темата *„Екстремни температури и тяхното влияние върху минералните ресурси в Европа“*. След това изследователските въпроси се прецизират, за да дадат насока на проучването и оформлението на статията. По-нататък дискусиата очертава насоките за развитието на академичните умения в ерата на ИИ, посочвайки важноста на развиването на критично мислене и поддържането на методологична прецизност. В заключение статията потвърждава твърдението, че ИИ неизбежно ще стане неразривен елемент както от научните изследвания, така и от висшето образование, при условие че употребата му е зададена в стриктни етични рамки.

Ключови думи: изкуствен интелект (ИИ), университетско образование, генерирани от изкуствен интелект отговори, минерални ресурси, академични умения.

Introduction

Machines are becoming increasingly proficient at defining tasks and analysing data. Therefore, doctoral programs must evolve to maximise the use of artificial intelligence (AI). In 2022, the chatbot ChatGPT was launched. Since then, a debate has emerged within universities about AI, focusing primarily on undergraduate education—how to prevent misconduct and how to leverage AI to enhance learning. Parker et al. (2025) unearth a hybrid human-AI writing process characterised by dynamic brainstorming, continuous negotiation of meaning, and comparative evaluation. Emphasis on AI literacy and academic integrity is crucial for preparing graduates for an AI-integrated workforce. Oubibi, (2025) delves into the integration of generative AI tools, such as advanced text generation models, within the context of creative and academic writing among 109 postgraduate students in Thailand. The findings from this study reveal substantial enhancements in multiple dimensions of student engagement, including creative output, writing fluidity, and technological adaptability. But in research—the other core activity of universities—a change is being observed. Harris et al., (2025) examine the applications and perceptions of AI tools in doctoral studies, focusing on their efficacy in enhancing research effectiveness. A survey found that most participants used AI tools in their doctoral studies (63%), with the majority of those users reporting some positive impact from their usage. Sabbaghan et al. (2025) explore graduate students' perceptions of using a generative AI-powered research application, COREI, and its impact on their sense of intellectual and scholarly ethics. Semi-structured interviews were conducted with graduate students ($n = 10$), four doctoral and six masters', from a large

research university in Western Canada. The findings suggest a need for reconceptualising traditional notions of agency, authorship, and originality in the context of AI-assisted research. The study highlights the importance of developing ethical frameworks and institutional policies that prioritise human agency and critical engagement with AI-generated content, while also emphasising the need for further research on the long-term impacts of generative AI on intellectual and scholarly ethics. Most universities are unprepared for the scale of change, with few having management strategies in place. Many academic institutions remain focused on the shortcomings of early generative tools, such as hallucinations (confidently stated but incorrect information), contradictions, and superficial responses. However, by 2025, AI models are becoming increasingly accurate. As noted by Nordling (2025), doctoral students are calling for less harassment and adequate supervision. Lambe (2025) describes various strategies for finding joy in doctoral work. AI tools are now capable of writing literature reviews, producing complex code with human assistance, and even generating hypotheses when provided with large datasets. AI agents that can set their own sub-goals, coordinate tasks, and learn from feedback represent a significant leap forward. If this trend continues, we may reach a point where conventional doctoral work can be carried out—or at least substantially supported—by machines. Grote et al., (2024) present findings from a broad, national survey and a workshop focusing on the challenges and opportunities the advancement of AI poses for PhD candidates, seen from the perspective of library staff working with research support in several research libraries in Norway. For the development of competences of teaching staff in academic libraries, the paper

recommends integrating AI-related topics into existing educational resources and creating arenas for sharing experiences and knowledge with relevant partners both within and outside the university. Rafi & Amjad, (2025) emphasise the need for significant institutional investments in AI-integrated writing platforms to open, widen, and deepen discussion on dissertation writing – a strategy to strike a balance between GenAI and human interactions. This change presents challenges for faculties. Gupta (2025a) shows how AI could be helpful in PhD students' education. "What does it mean for an original contribution not to be accepted when an AI tool creates the literature review, gathers and analyses data, and writes chapters of the dissertation?" The role of a faculty is to teach students how to formulate questions and verify answers. The University of Washington (UW) Graduate School (2024) exhibits questions to be input to ChatGPT and CoPilot and the corresponding AI generated answers. The UW Graduate School add other questions to provide an example of the variability of the output received from the same question. The research consists of an incomplete list of 20 AI tools for research and writing, generated by CoPilot. Gupta (2025b) simulates the execution of a doctoral project by AI, examining how extreme ocean temperatures affect marine species. But before that, a study must be conducted on how AI can assist doctoral students.

Methodology

The method includes AI's recommendations on *How climate changes impact mineral resources in Europe*. Below, we outline the discussion:

I asked AI how climate change affects mineral resources in Europe.

Mila, I'd recommend prioritising:

- **GIS + AI overlays** for mapping mineral belts and heatwave vulnerability.
- **Elicit.org + Copilot** for synthesising climate-mineral literature.
- **DeepL Write** for bilingual abstracts and keywords.

Would you like me to **map these tools into your actual workflow** (e.g., literature review → mapping → writing → submission), so you have a step-by-step AI integration plan for your PhD article?

Yes, please.

Step 1: Literature Review

- **Tools:**
 - *Elicit.org* → Extracts methods, results, and gaps from papers.
 - *Semantic Scholar / Research Rabbit* → Citation networks and related works.
 - *Copilot* → Summarises articles, generates keywords, and refines abstracts.
- **Workflow:**
 - Use Elicit to gather structured insights from climate–mineral studies.
 - Build citation maps with Research Rabbit to visualise research clusters.
 - Ask Copilot to synthesise findings into a coherent narrative and generate bilingual keywords (English–Bulgarian).

Step 2: Mapping & Data Analysis

- **Tools:**
 - *QGIS / ArcGIS with AI plugins* → Geospatial overlays of mineral belts and heatwave zones.
 - *Python ML libraries (scikit-learn, TensorFlow)* → Detect climate vulnerability patterns.
 - *Copilot visualisation mode* → Quick charts and graphs for exploratory analysis.
- **Workflow:**
 - Import mineral belt datasets into QGIS.
 - Overlay climate vulnerability indices (heatwave frequency, drought zones).
 - Use AI clustering (e.g., k-means) to identify instability hotspots.
 - Generate maps and graphs for inclusion in your article.

Step 3: Writing & Drafting

- **Tools:**
 - *Copilot* → Draft abstracts, introductions, and refine structure.
 - *Grammarly / DeepL Write* → Language polishing and translation.
 - *Scholarcy* → Summarize supporting papers into digestible notes.
- **Workflow:**
 - Draft your abstract with Copilot, focusing on clarity and impact.
 - Use Grammarly for style refinement and DeepL for bilingual precision.
 - Summarise supporting literature with Scholarcy to keep references concise.

Step 4: Ethics & Integrity

- **Tools:**
 - *Turnitin with AI detection* → Check originality.
 - *Zotero / EndNote* → Manage references properly.
 - *University AI guidelines (e.g., UW Graduate School)* → Ensure compliance.
- **Workflow:**
 - Run drafts through Turnitin to confirm originality.
 - Organise references with Zotero, ensuring correct citation formats.
 - Align your AI usage with institutional guidelines for transparency.

Step 5: Submission & Collaboration

- **Tools:**
 - *Overleaf with AI assistants* → Collaborative LaTeX writing.
 - *Mendeley + AI search* → Reference organisation and discovery.
 - *Copilot Pages* → Refine drafts and prepare submission-ready materials.
- **Workflow:**
 - Finalise manuscript in Overleaf for journal formatting.
 - Double-check references with Mendeley.
 - Use Copilot Pages to polish your article and prepare keywords/abstract for submission.

Mila, this plan integrates AI at every stage: **discover** → **analyse** → **write** → **validate** → **publish**. It keeps you efficient while safeguarding originality and rigor. Would you like me to **design a visual flowchart of this workflow** (from literature review to

submission) so you can use it as a reference in your research notes?

Yes, please!

Unfortunately, two attempts were not successful. AI only produced a description of the steps, which we used to construct the flowchart ourselves (Fig. 1).

Results

The results include the specific questions we posed to Copilot in order to elaborate on *How extreme temperatures affect mineral resources in Europe*.

1. Give core scientific questions.
2. Make regional targets for analysis.
3. List deposit forming minerals.
4. Explain Heatwave Impact mechanisms on Mineral Deposits.
5. Draw a Computational Plan.
6. Show How a Machine Learning Model works.
7. Exhibit Model Logic.
8. Demonstrate a Machine Learning Simulation.
9. Perform Predictive Modelling of Mineral Instability in European Heatwave zones.
10. Write Future Heatwave scenarios.
11. Overlay maps of European Mineral Belts and European Heatwave Zones.
12. Write Conclusion with future work.
13. Write Literature.
14. Write an Introduction.
15. Write an Abstract.

The next result will be illustrated and discussed in a separate article of ours: **“Heatwave-Induced Mineral Instability across Europe”**.

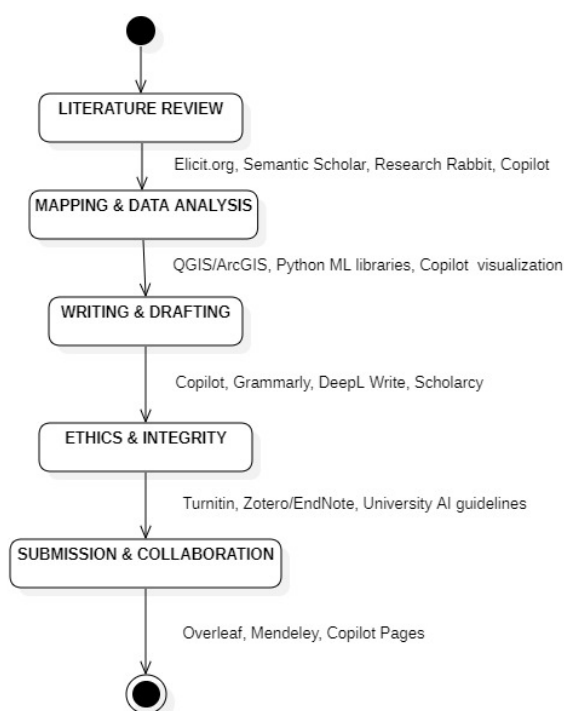


Fig. 1. Flowchart of AI integration in PhD research (article) workflow

Discussion

Academic skills

The experiment has convinced us that training in academic skills will need to be fundamentally reconsidered along the following lines:

1. Students will need to develop sufficient expertise to identify when AI systems produce plausible but inaccurate results—a dilemma, since this requires many of the very skills that AI is beginning to replace.

2. Training in oral defence, live problem-solving, and subsequent commentary on research decisions is far more important than a written article or dissertation.

3. The structure of doctoral programs will need to be reconsidered. Universities will have to decide whether to shorten doctoral programs or to broaden their scope in order to address more ambitious, potentially interdisciplinary problems.

4. Safeguarding students' development is a critical measure, as (over)reliance on AI may lead to intellectual atrophy across a range of skills. Abilities, such as critical reading, analytical reasoning, and scientific writing, must be practiced regularly. This requires deliberate academic intervention.

5. Developing recommendations for the use of AI should focus primarily on academic integrity—for example, requiring disclosure of AI assistance and limiting its use to supportive roles rather than fully replacing research writing. Mandatory courses in AI literacy could be introduced into undergraduate and PhD curricula. The absence of such programs may result in long-term inequality in research capacity.

6. Consulting with AI can help identify new research directions, suggest methodological approaches, and even propose analytical frameworks, while also enabling observation of how AI performs complex analyses on real data. For those who do not use AI tools regularly, the complexity of such outputs may be unsettling. Therefore, students and doctoral candidates must adapt to this new reality.

Geophysical validation as a framework for AI-integrated academic training

The rapid integration of artificial intelligence into academic research has enhanced modelling capacity and predictive performance in geoscience. As Degen pointed, an accurate assessment of the physical states of the Earth system is an essential component of many scientific, societal, and economical considerations (Degen, et al. 2023). However, statistical accuracy alone does not guarantee physical validity. This paper proposes a structured framework in which geophysical monitoring functions as a validation and calibration mechanism for machine learning (ML) predictions. According to Li and colleagues, machine learning has significantly revolutionised scientific methodology in geoscience applications by introducing automation, enhancing efficiency, enabling adaptability, ensuring security, and facilitating extensive data analytics (Li, et al., 2023,). With a step forward, by embedding an iterative AI–Geophysics validation loop into academic workflows, PhD candidates develop critical AI literacy, interpretative autonomy, and physics-informed reasoning. The framework transforms AI from a black-box predictor into a hypothesis-generating partner whose outputs must be tested against measurable subsurface processes. This approach strengthens methodological accuracy, while encouraging

responsible and scientifically grounded AI integration in doctoral training.

Artificial intelligence is increasingly embedded in academic and doctoral research workflows, supporting literature synthesis, predictive modelling, and data interpretation. While these tools improve efficiency and analytical depth, they also introduce some risks - physically inconsistent or geologically implausible results.

In applied geoscience, predictive ML models often operate in complex, multi-parameter environments characterised by ambiguity and uniqueness. Without physical constraints, models may identify statistical correlations, which leads to geological inconsistency. Therefore, doctoral training must extend beyond AI usage toward *AI validation*.

It has been demonstrated that interpretable neural network techniques can provide insights into model behaviour beyond simple accuracy metrics, offering better alignment with geophysical processes (Toms et al., 2021). We propose a scientific framework in which geophysical monitoring is systematically integrated into AI-driven modelling. This approach establishes an iterative validation mechanism that aligns statistical prediction with measurable subsurface reality.

The proposed framework consists of a four-stage architecture designed for doctoral research in AI-integrated geoscience.

Stage 1 – Predictive AI Modelling

A supervised machine learning model generates a quantitative prediction (e.g., Instability Score, Risk Index, or Structural Integrity Metric) based on structured inputs such as:

- Climatic anomalies
- Geological parameters
- Deposit depth
- Mineralogical composition
- Hydrothermal indicators

Stage 2 – Geophysical Measurement

Doctoral researchers evaluate whether predicted instability manifests in measurable subsurface responses using time-lapse or monitoring techniques such as:

- Electrical resistivity tomography (ERT)
- Induced polarisation (IP)
- Seismic velocity measurements (ΔV_p)
- Self-potential (SP) monitoring

Stage 3 – Comparative consistency analysis

The predicted AI output (e.g., Instability Score, or IS) is compared with the measured Geophysical Response Index (GRI):

- If $IS \approx GRI \rightarrow$ the model demonstrates physical consistency.
- If $IS \neq GRI \rightarrow$ the model requires recalibration.

Stage 4 – Iterative model refinement

When inconsistencies arise, doctoral researchers engage in structured recalibration:

- Inclusion of geophysical parameters as additional features
- Adjustment of model parameters
- Reassessment of some parameters for geological plausibility

The model is retrained and re-evaluated, closing the validation loop.

The AI–Geophysics iterative validation loop (Fig. 2.) illustrates a structured doctoral workflow in which machine learning predictions are continuously evaluated and adjust with accordance to geophysical responses. This mechanism enhances interpretability, enforces physical consistency, and encourages critical thinking.

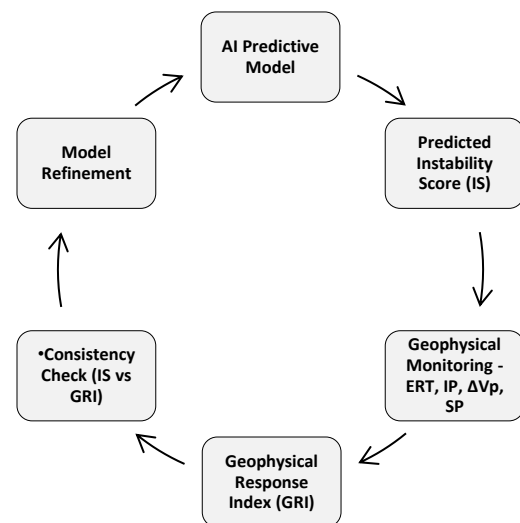


Fig. 2. The AI–Geophysics iterative validation loop

Embedding geophysical validation into AI-driven modelling represents both a methodological advancement and a pedagogical innovation. Through the AI–Geophysics iterative validation loop, doctoral researchers learn to critically evaluate model outputs and to use prediction with physical reality. This multidimensional thinking is essential for responsible AI-assisted research.

Conclusion

The role of artificial intelligence in doctoral research is expected to expand significantly over the next decade, reshaping both methodology and pedagogy. AI will increasingly serve as a co-researcher, automating repetitive tasks, such as literature synthesis, data cleaning, and visualisation, while enabling PhD candidates to focus on originality and critical inquiry. Advanced natural language models will evolve into multilingual writing partners, reducing barriers for international scholars and fostering more inclusive participation in global science.

In data-intensive fields, AI-driven analytics and geospatial modelling will become standard practice, allowing doctoral students to uncover complex patterns in all topics of our life. At the same time, universities will formalise ethical frameworks to ensure transparency, authorship integrity, and responsible use of AI. Doctoral training programs are likely to incorporate AI literacy as a core competency, preparing candidates for careers in academia and industry where hybrid human–machine collaboration is the norm.

Overall, the prognosis suggests that AI will not replace the intellectual rigor of PhD research but will act as a catalyst—accelerating discovery, enhancing interdisciplinarity, and democratising access to advanced research tools. The

challenge will lie in balancing efficiency with originality, ensuring that doctoral research remains a space for innovation, critical thought, and ethical scholarship.

References

- Degen, D., Caviedes Voullieme D., Buiter, S., Freeberg, Hendricks Franssen, J.-H., Vereecken, H., Gonzalez-Nicolas, A., and Wellmann, F. (2023) Perspectives of physics-based machine learning strategies for geoscientific applications governed by partial differential equations. *Geosci. Model Dev.*, 16, 7375-7409, <https://doi.org/10.5194/gmd-16-7375-2023>
- Grote, M., Faber, H., G., L., Gasparini, A. (2024) Artificial Intelligence in PhD education: New Perspectives for research Libraries. *LIBER Quarterly: The Journal of the Association of European Research Libraries*, Vol. 34, No. 1 (2024) <https://doi.org/10.53377/lq.18137>
- Gupta A. S. (2025a). PhD training needs a reboot in an AI world. *Nature*, PhD training needs a reboot in an AI world
- Gupta A. S. (2025b). “Supplementary information to: PhD training needs a reboot in an AI world”, An Essay published in *Nature* 647, 27–28 (2025) <https://doi.org/10.1038/d41586-025-03572-w>
- Harris, M., Soriano, N., Ralston, N. (2025) An Examination of the Use of AI (Artificial Intelligence) Technology as Experienced by Scholarly Practitioners in an Educational Doctorate Program. *Impacting Education: Journal of Transforming Professional Practice*, Vol. 10, No. 1 (2025) <https://doi.org/10.5195/ie.2025.472>
- Lambe, R., (2025) Stressed out by PhD Life? Five Strategies to take back the joy. *Nature*. Stressed out by PhD life? Five strategies to take back the joy
- Li, Y., E., O'Maley, D., Beroza, G., Curtis, A., Johnson, P. (2023) Machine Learning Developments and Applications in Solid Earth Geosciences: Fad or Future? *J. Geophys. Res. Solid Earth*, 2023, 128, e2022JB026310.
- Nordling, L. (2025) How money, politics and technology are redefining the PhD experience in 2025. *Nature*. How money, politics and technology are redefining the PhD experience in 2025
- Oubibi, M. (2025) Generative Artificial Intelligence: Postgraduate student's digital adaptability, engagement and academic confidence. *J. Comput. Educ.* <https://doi.org/10.1007/s40692-025-00364-z>
- Parker, J. L., Richard, V.M., Acaba, A. et al. (2025) Negotiating Meaning with Machines: AI's role in Doctoral Writing Pedagogy. *Int. J. Artif. Intell. Educ.* <https://doi.org/10.1007/s40593-024-00425-x>
- Rafi, M., S., Amjad, I. (2025) The Role of Generative AI in writing doctoral dissertation: perceived opportunities, challenges, and facilitating strategies to promote human agency. *Discov. Educ.* 4, 165 <https://doi.org/10.1007/s44217-025-00503-9>
- Sabbaghan, S., Eaton, S. E. (2025) Navigating the Ethical Frontier: Graduate Students' Experiences with generative AI-Mediated Scholarship. *Int. J. Artif. Intell. Educ.* <https://doi.org/10.1007/s40593-024-00454-6>
- Toms, B., A., Kashinath, K., Prabhat, and Yang, D. (2021) Testing the reliability of interpretable neural networks in geoscience using the Madden-Julian oscillation. *Geosci. Model. Dev.* 14, 4495-4508, <https://doi.org/10.5194/gmd-14-4495-2021>
- University of Washington Graduate School. (2024). Effective and responsible use of AI in Research: Effective and responsible Use of AI and Research Guidance for Performing Graduate Research and in Writing Dissertations, Theses, and Manuscripts for Publications. Effective and Responsible Use of AI in Research – UW Graduate School