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AN INTERDISCIPLINARY MODEL FOR TEACHING WITH OPEN CLIMATE DATA ACROSS MATHEMATICS, INFORMATICS, AND GEOGRAPHY

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Abstract. This paper presents an interdisciplinary educational model that integrates open climate data into the teaching of informatics, mathematics, and geography, with a focus on developing data literacy, geospatial thinking, and climate awareness. Using datasets from the Copernicus Climate Data Store (CDS) and open-source tools, we designed and tested a series of interactive lessons in Jupyter Notebooks that focus on climate data visualization, time series analysis, and spatial patterns of temperature change. The lessons were successfully implemented using open software such as Python and QGIS, and they introduced students to key STEM competencies, including computational thinking, geostatistical reasoning, and environmental interpretation. The model proved effective in enhancing student engagement, improving comprehension of abstract climate concepts, and developing digital competencies relevant to the 21st-century classroom. By offering a flexible structure adaptable to different technological contexts and curriculum profiles, the model contributes to climate education by providing scalable, open-access resources that support interdisciplinary learning aligned with EU digital and green education priorities.

Keywords: STEM; climate change; open data; open-source software, interdisciplinary learning

1. Introduction

In the context of accelerating climate change, a high number of disasters happening worldwide, and the growing importance of digital and environmental literacy, education systems around the world are called upon to respond with more integrated and data-driven approaches. In Bulgaria, the national curriculum emphasizes STEM education and environmental awareness, but the practical integration of real-world climate data into learning activities remains limited in the Mathematics, Informatics, Information Systems, and Geography curricula. At the same time, open data sources such as the Copernicus Climate Data Store (CDS), the Bulgarian Open Data Portal, and the National Statistics Institute's registry provide free access to high-quality climate and disaster datasets. These resources offer an opportunity to engage students not only with scientific content, but also with basic skills in mathematics, informatics, computer science, and geography.

Data literacy is gradually being integrated into Bulgarian secondary education through subjects like Mathematics (all grades), Informatics (8th grade), and Information Technology (5th – 10th grade)[7]. Geography also includes data analysis in topics such as climate, meteorology, and economics. Schools vary in their focus and tools – using software like Excel, GeoGebra, GIS, and programming languages such as Scratch, Python, C++, and Java. Educational profiles differ in depth and emphasis on STEM and informatics.

This model is adaptable to varying levels of prior knowledge. It suits students with basic skills in spreadsheets or introductory programming (e.g., Python or Scratch) and also supports beginners through simplified exercises. Informatics covers data processing, algorithms, and programming, with Python now widely used. Information Technology includes databases, spreadsheets, and other digital tools relevant to everyday and professional contexts.

Data science education in Bulgarian secondary schools is evolving to equip students with skills in data analysis and programming, primarily through Informatics and Information Technologies. Despite variation between schools, the overall trend emphasizes working with data. Open data—central to the EU's transparency agenda—is increasingly accessible via national platforms like data.egov.bg and inspire.egov.bg, supporting education, research, innovation, and informed civic engagement.

A growing number of publications emphasize the value of interdisciplinary, inquiry-based approaches to STEM education, especially in relation to climate and environmental topics. For example, (Barrett 2014), (Czerniak & Johnson 2014) and (Johnson & Czerniak 2023) provide foundational insights into integrated STEM teaching, which our model builds upon by offering practical, open-source resources tailored to secondary school use, while (Al Salami et al. 2017) investigates shifts in teacher attitudes, highlighting the need for teacher support in interdisciplinary contexts – a challenge also reflected in our implementation.

Other studies focus on the use of public or environmental datasets in education. Solakis & Atanasova (2025) and Hoic-Bozic et al. (2019), for instance, examine the incorporation of GIS and computational thinking, which aligns closely with our inclusion of QGIS and Python. In addition, Sun, Dyer & Harris (2024) and Clark et al. (2015) further confirm the educational value of real-time weather data for STEM literacy. Our approach differs by combining these elements into a cohesive, reproducible teaching framework based on open climate data.

The potential of climate change as a context for multidisciplinary learning is also well documented. Studies such as (Urban et al. 2018), (McCright et al. 2013), and (Rogers et al. 2015) show that sustainability themes enhance student motivation and understanding across disciplines. Similar results are reported in (Misheva 2020), which uses creative methods in geographic education. Environmental science is framed as a natural fit for STEM integration (Geidel & Winner 2016) – a view that our study operationalizes through classroom-ready, curriculum-aligned materials.

Although there is existing research on the topic, the use of interdisciplinary teaching methods based on programming languages such as Python and open data derived from official sources to solve real-world geographical problems remains underexplored and poorly implemented in practice, primarily due to the recent emergence of relevant technologies, the relatively new availability of accessible data, and the significant role of teachers' digital literacy as a determining factor.

This paper presents a structured model for integrating open climate data into interdisciplinary STEM lessons in the Bulgarian educational context. By using European datasets, such as ERA5, we demonstrate how students can explore heat waves, long-term temperature trends, and spatial climate variability through open data and visualizations. Through lesson scenarios, we show how open data can support project-based learning, analytical thinking, and cross-curricular connections.

2. Methods and data

The UNESCO Digital Literacy Global Framework (DLGF) provides a comprehensive and internationally recognized structure for defining the digital competencies needed for learners and educators alike. Table 5 in the framework outlines proposed competence areas and detailed descriptors that align with the goals of this paper, especially in the context of teaching with open climate data. In Table 1, we have selected specific competencies from this framework that are not only directly relevant to the use of real-world datasets in education, but also support interdisciplinary and project-based learning across mathematics, informatics, and geography. They were used as a methodological baseline in the process of preparing the model lessons. These competencies were chosen because they emphasize skills in data analysis, software operation, digital citizenship, and computational thinking – all of which are central to meaningful engagement with climate data.

Table 1. The UNESCO Digital Literacy Global Framework competence areas that were selected for the study

Competency	Description
0. Devices and Software Operations	
0.2. Software operations in digital devices	To know and understand the data, information, and/or digital content that are needed to operate software tools and technologies.
1. Information and Data Literacy	
1.1. Browsing, searching, and filtering data, information, and digital content	To articulate information needs, to search for data in digital environments, and to create effective search strategies.

1.2. Evaluating data, information, and digital content	To critically assess the credibility, relevance, and accuracy of sources and data.
1.3. Managing data, information, and digital content	To organise, store, and process information in structured digital environments.
2. Communication and Collaboration	
2.3. Engaging in citizenship through digital technologies	To participate in society using digital services and seek self-empowerment through digital tools.
3. Digital Content Creation	
3.3. Copyright and licences	To understand legal frameworks regarding the use and sharing of digital data and content.
3.4 Programming	To plan and develop understandable sequences of instructions for solving problems.
5. Problem Solving	
5.3 Creatively using digital technologies	To create new knowledge and digital products through innovation and cognitive processing.
5.4 Identifying digital competence gaps	To evaluate and improve one's own digital skills and help others do the same.
5.5 Computational thinking	To deconstruct problems into sequential, logical steps suitable for solving with computers.

The selected competencies are embedded throughout the interdisciplinary model. In informatics, students write Python scripts to process and visualize climate data (3.4, 5.5). In geography, they use GIS tools to map spatial patterns and analyze regional variations (0.2, 1.1, 1.3). Mathematics tasks include trend analysis and anomaly calculations, reinforcing data evaluation skills (1.2, 1.3). The use of open climate data also promotes digital citizenship (2.3), copyright awareness (3.3), and problem-solving (5.3, 5.4), making the framework a strong foundation for future-oriented, interdisciplinary education.

As global climate challenges intensify, educational frameworks must adapt to equip students not only with scientific knowledge, but also with the competencies needed to understand, evaluate, and act upon environmental issues. The PISA 2025 Science Framework, developed by the Organisation for Economic Co-operation and Development (OECD), reflects this shift by redefining the expectations for 15-year-olds in terms of scientific literacy and environmental knowledge. The framework introduces a broader set of outcomes, recognizing that education must prepare learners to think critically, interpret evidence, engage in systems thinking, and act with responsibility and hope in the face of socio-ecological crises. The competencies that we selected for our current work (Table 2) are central to our interdisciplinary teaching model, especially in relation to using real climate data to explore and communicate the causes and consequences of phenomena like heatwaves and long-term warming. Through data-driven education, students are encouraged not only to learn about the climate, but to become agents of change within their communities.

Table 2. Selected Competencies from the PISA 2025 Science Framework (OECD)

Competency	**Description**
Science Competencies	
Explain phenomena scientifically	To use knowledge of science to explain and predict phenomena in natural and technological environments.
Construct and evaluate designs for scientific enquiry and interpret	To understand how data is generated, interpret evidence, and

scientific data and evidence critically	assess the quality and implications of scientific conclusions.
Research, evaluate, and use scientific information for decision making and action	To identify and evaluate credible sources, weigh different perspectives, and apply scientific understanding in real-world contexts.
Environmental Science Competencies (Agency in the Anthropocene)	
Explain the impact of human interactions with Earth's systems	To understand how human actions—such as energy consumption, land use, and emissions—affect ecological balance and climate systems.
Make informed decisions to act based on evaluation of diverse sources of evidence and application of creative and systems thinking	To synthesize information from scientific, social, and ethical perspectives and use systems thinking to propose sustainable actions.
Demonstrate respect for diverse perspectives and hope in seeking solutions to socio-ecological crises	To cultivate constructive dialogue, empathy, and optimism in addressing shared global challenges like climate change.

These competencies align with the goals of this paper, supporting student engagement with scientific inquiry through maps, visualizations, and code. By analyzing temperature trends and local impacts like urban heat islands, students connect human activity with climate systems. Group work and citizen science also foster ethical and civic thinking, reflecting the OECD's vision for education in the Anthropocene.

2.1. Data sources and software

This study is based exclusively on open datasets from the Copernicus Climate Change Service (C3S). While national climate data providers such as Bulgaria's National Institute of Meteorology and Hydrology (NIMH) play a crucial role in weather monitoring and forecasting, their data is not fully accessible or available in machine-readable formats. Due to this limitation, we rely entirely on open international data platforms to demonstrate reproducible, data-driven education in the classroom.

The primary data source used in all three lesson scenarios is the ERA5 dataset accessed through the Copernicus Climate Data Store (CDS). It provides consistent, long-term, and high-resolution reanalysis data, which is ideal for interdisciplinary climate education. For secondary education teachers and students, this open-access platform offers both direct download options (CSV, NetCDF) and a no-code web-based visualization interface. The CDS is the central platform of the Copernicus Climate Change Service (C3S 2017), operated by the European Centre for Medium-Range Weather Forecasts (ECMWF). It provides a wide range of datasets relevant to climate research and education, including long-term historical reanalysis products such as ERA5. It offers hourly estimates of atmospheric, land, and oceanic variables dating back to 1950, with global coverage and a spatial resolution of approximately 30 km.

ERA5 data is central to this educational model due to its consistency, long-term coverage, and key climate variables such as temperature, precipitation, and solar radiation. Accessible via the CDS API, it supports reproducible workflows in Python using libraries like *cdsapi, xarray*, and *Matplotlib.* The ERA5 Explorer offers a no-code interface for generating climate stripes and time series, making it ideal for student use. These visualizations effectively convey climate change patterns at global and local scales.

All data used in the study come from the Copernicus Climate Change Service (C3S). For local analysis, ERA5 Explorer was used to extract daily temperature data for Sofia and Plovdiv in CSV format. Jupyter Notebooks were created from this data for classroom use. Future heatwave projections were sourced from the CDS "Heatwaves and Cold Spells in Europe" dataset (Hooyberghs et al. 2019) and visualized in QGIS using NetCDF files.

Bulgarian secondary schools use a variety of software tools to build students' digital skills. Microsoft Office is widely used for creating documents, spreadsheets, and presentations. SQL is introduced in IT subjects for querying and managing relational databases. Python is taught in programming courses due to its simplicity and relevance for tasks like algorithms and data processing. GIS, especially QGIS, is included in 12th-grade geography, helping students analyze spatial data and understand environmental processes.

As there are a variety of profiles available across the country, in this paper we will focus on the data processing and its usage in the classroom in terms of analysis and visualization. There are plenty of possibilities for using this methodology in other software, programming languages, and also with other data, allowing teachers to choose the most suitable option for their specific needs. For example, instead of Jupyter Notebooks and Python, teachers may use Excel to plot temperature trends and generate basic statistics. Climate stripe visuals can be created using conditional formatting in spreadsheets. In schools using GeoGebra or Google Earth Engine, spatial analysis can be done by importing climate datasets via CSV or web services. These flexible pathways allow educators to align the model with available infrastructure and student proficiency.

2.2. Educational framework and methodology

The methodological framework (Fig. 1) is based on the use of open-source software environments that facilitate both code-based and visual approaches to climate data analysis. Python, accessed through Jupyter Notebooks, was employed for the loading, transformation, and visualization of tabular climate datasets (CSV format), utilizing libraries such as *pandas* and *NumPy* for data processing, and *Matplotlib* for generating line charts, heatmaps, and climate stripes. For geospatial data visualization, particularly of projected climate indicators in NetCDF format, we used QGIS—an open-source Geographic Information System that enables students to import, style, and interpret multi-dimensional datasets with spatial context. All instructional materials and model notebooks are published on GitHub to ensure transparency, reproducibility, and broad accessibility in educational settings.

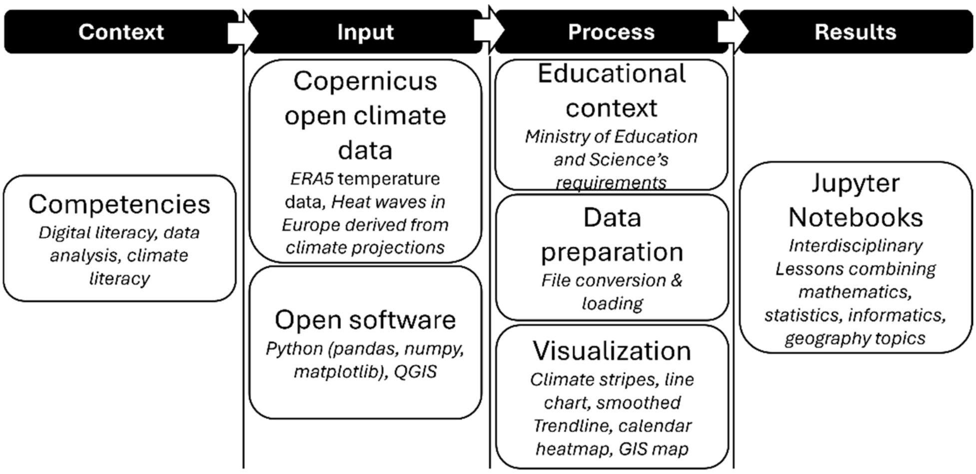


Figure 1. Methodology of the study.

To support immediate use without the need for software installation, the notebooks are also deployed via Binder, allowing students and educators to interact with the materials directly in the browser.

3. Results

The integration of mathematics, informatics, and geography through the use of open climate data and free analytical tools presents a powerful methodological approach to interdisciplinary education, particularly in specialized secondary schools. The resulting sample lessons are listed in Table 3.

Table 3. List of resulting notebooks

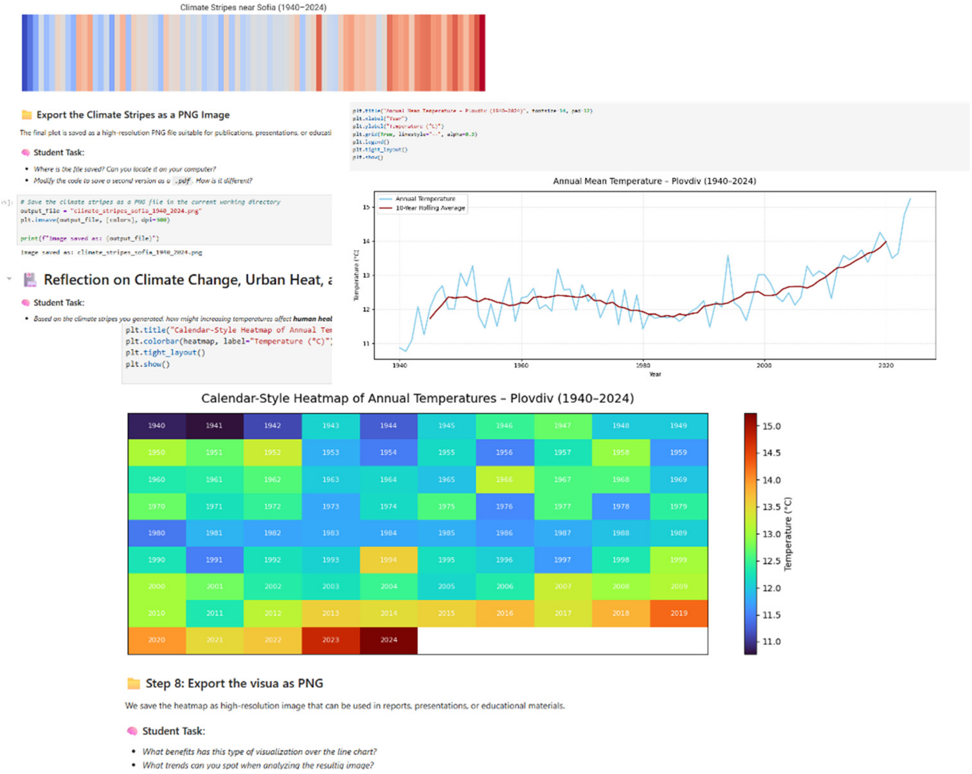
Lesson Name	Focus	Location	Repository
Climate Stripes in Sofia, Bulgaria	Visualizing long-term warming via climate stripes	**Sofia**	**GitHub**[2]
Climate Trends in Plovdiv, Bulgaria	Trendlines and calendar heatmaps of yearly temperature	**Plovdiv**	**GitHub**[4]

Copernicus & QGIS Climate Data Visualization Guide	Markdown-only tutorial for downloading NetCDF and QGIS use	**Europe** (future heatwave projections)	**GitHub**[6]

By engaging students in the analysis of real-world datasets—such as long-term climate records or future heatwave projections—learners are introduced to fundamental statistical concepts (e.g., mean, standard deviation, anomaly, trend) within an applied context, enhancing both their mathematical literacy and critical thinking. Also, the use of programming in Python introduces core competencies in informatics and computational thinking, as students learn to manipulate, visualize, and interpret large datasets using professional libraries like *pandas*, *Matplotlib*, and *xarray*. These technical skills are then grounded geographically, as the spatial dimensions of climate data are explored through maps, location-based analysis, and integration into Geographic Information Systems (e.g., QGIS).

The open-access nature of the climate data (sourced from the Copernicus Climate Data Store) and the software tools employed (Python, Jupyter Notebooks, QGIS) ensure not only transparency and reproducibility, but also equity in access to high-quality educational content. The publication of these teaching materials via GitHub and their deployment through Binder allows students and teachers to run and interact with the notebooks directly in the browser without requiring any local installation.

The structure of the notebooks (Fig. 2) begins with an introduction that outlines the learning goals and scientific context, followed by a data description section explaining the origin, format, and significance of the data used (e.g., Copernicus Climate Data Store, libraries used, etc.). The core analytical process is laid out in step-by-step code blocks with explanatory comments to foster computational thinking. To reinforce critical understanding, each notebook includes a “Student Task” section with questions, and a “Reflection” at the end of the notebook, where students relate the analysis to broader environmental or societal issues. This final segment encourages extension activities and independent inquiry. This modular structure not only facilitates reproducible research but also aligns with inquiry-based STEM education practices by integrating scientific reasoning with digital literacy. This model democratizes the use of complex scientific resources and provides a pedagogically rich environment in which students can explore climate change, environmental challenges, and data-driven storytelling through a genuinely interdisciplinary lens. Assessment within this model is formative and multidimensional. Technical skills such as coding and GIS usage are evaluated through completion of notebook exercises and accuracy of outputs (e.g., correct plots, maps). Conceptual understanding is assessed through written reflections, guided discussion questions, and tasks requiring students to interpret climate indicators. Digital and problem-solving competencies are evaluated based on students' ability to troubleshoot errors, collaborate on group tasks, and use open data responsibly, often aligned with descriptors from the UNESCO Digital Literacy Framework.



Export the Climate Stripes as a PNG Image

The final plot is saved as a high-resolution PNG file suitable for publications, presentations, or educati

Student Task:

- *Where is the file saved? Can you locate it on your computer?*
- *Modify the code to save a second version as a `.pdf`. How is it different?*

```
# Save the climate stripes as a PNG file in the current working directory
output_file = "climate_stripes_sofia_1940_2024.png"
plt.imsave(output_file, [colors], dpi=300)

print(f"Image saved as: {output_file}")
```

```
Image saved as: climate_stripes_sofia_1940_2024.png
```

Reflection on Climate Change, Urban Heat, a

Student Task:

- *Based on the climate stripes you generated, how might increasing temperatures affect **human heal***

```
plt.title("Calendar-Style Heatmap of Annual Te
plt.colorbar(heatmap, label="Temperature (°C)"
plt.tight_layout()
plt.show()
```

```
plt.title("Annual Mean Temperature – Plovdiv (1940–2024)", fontsize=14, pad=12)
plt.xlabel("Year")
plt.ylabel("Temperature (°C)")
plt.grid(True, linestyle="--", alpha=0.3)
plt.legend()
plt.tight_layout()
plt.show()
```

1940	1941	1942	1943	1944	1945	1946	1947	1948	1949
1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2020	2021	2022	2023	2024					

Step 8: Export the visua as PNG

We save the heatmap as high-resolution image that can be used in reports, presentations, or educational materials.

Student Task:

- *What benefits has this type of visualization over the line chart?*
- *What trends can you spot when analyzing the resultiq image?*

Figure 2. Study results as data visualizations in Jupyter Notebooks

4. Discussion

The integration of open climate data into interdisciplinary education sits at the intersection of multiple rapidly evolving domains – climate science, digital technologies, and data literacy. This dynamic context presents both extraordinary opportunities and critical challenges for educators and curriculum developers. Unlike traditional content areas that maintain relative stability over time, the field of open environmental data is inherently volatile. Technological platforms, data portals, and software tools that are widely used today may become obsolete or unsupported within just a few years. Consequently, educational methodologies built upon these resources must be viewed as inherently time-sensitive, with an anticipated functional lifespan of no more than five years.

This short lifecycle is driven by several interrelated factors. First, the pace of innovation in data science and geospatial technologies demands frequent revisions of learning materials to reflect current tools, standards, and workflows. Just a decade ago, curriculum updates occurred over many years of usage, but educators must now revise teaching scenarios annually or even more frequently to remain relevant. Second, the growing prevalence of artificial intelligence in data processing and analysis introduces a new layer of complexity. Students must now acquire not only basic statistical and programming skills, but also foundational AI literacy – understanding how machine learning models interact with data, and how such models may influence decision-making in climate and environmental science.

Equally essential is the need to continuously monitor and assess the availability and structure of open data sources. Platforms like the Copernicus Climate Data Store or ERA5 Explorer regularly update datasets, interfaces, and file formats, requiring both teachers and students to adapt their workflows accordingly. Educators must be trained not only to use these systems but also to teach students how to independently navigate and evaluate diverse sources of environmental information. This adds another layer of urgency to the conversation around professional development: as the ecosystem of tools and data grows more complex, there is a corresponding and continuous need for teacher training – not as a one-time intervention, but as an embedded and ongoing component of educational practice.

In this context, interdisciplinary models that leverage open software (e.g., Python, QGIS), shared platforms (e.g., GitHub, Binder), and open data are both pedagogically rich and logistically fragile. Their success depends not only on sound instructional design but also on the capacity of teachers and institutions to remain agile and up-to-date. Thus, while the approach described in this paper offers a compelling framework for modern climate education, it should be understood as a dynamic and iterative process—one that demands continuous revision, collaborative maintenance, and a strong institutional commitment to capacity-building in both digital and disciplinary expertise.

5. Conclusion

This study demonstrates the practical potential of integrating open climate data into interdisciplinary STEM education through a structured, scalable model rooted in real-world applications. By leveraging datasets from the Copernicus Climate Change Service—specifically ERA5 reanalysis data and future projections of heatwave days—we developed and implemented interactive lesson scenarios that connect geography, mathematics, informatics, and environmental science. These notebooks not only offer dynamic visualizations such as climate stripes, trend lines, and calendar heatmaps but also engage students in working with authentic scientific data and analytical tools used by professionals. The model highlights how open-source software environments (e.g., Python, QGIS, Jupyter Notebooks) and collaborative platforms (GitHub, Binder) can make climate education both accessible and methodologically robust. These learning activities are not only effective in building content knowledge, but also serve to operationalize the digital and scientific competencies outlined in Tables 1 and 2. For instance, writing Python code to load, transform, and plot temperature data directly addresses competencies 3.4 (Programming), 5.5 (Computational Thinking), and 1.3 (Managing Digital Content) from the UNESCO DLGF. Meanwhile, interpreting trend lines and anomaly maps builds understanding of climate phenomena, aligned with the OECD PISA 2025 competencies on explaining phenomena scientifically and evaluating evidence. Students' final reflections and project-based tasks also reflect engagement with environmental decision-making and systems thinking, contributing to competencies such as "Make informed decisions..." and "Demonstrate respect for diverse perspectives" (Table 2).

Beyond technical skills, the approach fosters a deeper understanding of climate variability, spatial patterns, and long-term environmental change—topics of increasing relevance for both scientific literacy and civic engagement. At the same time, the fast-changing nature of digital data platforms and tools signals the need for regular curriculum updates, teacher training, and an emphasis on developing transferable digital competencies, including AI literacy and data evaluation. While the methodology presented here is tailored to the Bulgarian context, its core principles are universally applicable. It serves as a replicable model for any educational system aiming to modernize science instruction, promote cross-disciplinary thinking, and empower students to interpret and act on pressing global challenges through open knowledge.

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NOTES

1. Climate Stripes Tutorial: https://cartography.bg/index.php/climate-stripes-tutorial/
2. Climate Stripes Tutorial, GitHub Repository: https://github.com/eugeniasarafova/climate-stripes-sofia
3. Annual Timeseries Tutorial: https://cartography.bg/index.php/annual-timeseries-tutorial/
4. Annual Timeseries Tutorial, GitHub Repository: https://github.com/eugeniasarafova/annual-timeseries-plovdiv

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