Yevhen Pashchenko,
Candidate of Economic Sciences,
Senior Researcher, Department of robotic systems,
Institute of Applied Control Systems of the NAS of Ukraine, Researcher,
Department for the Creation of Educational and Thematic Knowledge Systems,
National Centre "Junior Academy of Sciences of Ukraine",
Kyiv, Ukraine

https://orcid.org/0000-0001-8703-4796

Iryna Slipukhina,
Doctor of Pedagogical Sciences, Professor, Chief Researcher,
Department for the Creation of Educational and Thematic Knowledge Systems,
National Center "Junior Academy of Sciences of Ukraine",
Chief Researcher, Gifted Support Department,
Institute of Gifted Children of NAES of Ukraine,
Kyiv, Ukraine

https://orcid.org/0000-0002-9253-8021

Ihor Chernetskyi,
Candidate of Pedagogical Sciences,
Head of the Department
Creation of Educational and Thematic Knowledge Systems,
National Center "Junior Academy of Sciences of Ukraine",
Kyiv, Ukraine

https://orcid.org/0000-0001-9771-7830

UDC 37.091.3:55+004.8+37.02
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STEM APPROACH IN TEACHING GEOGRAPHY: USING ARTIFICIAL INTELLIGENCE TO STUDY MINERALS AND ROCKS

Summary.
The role of geological knowledge in modern society and its impact on the professions of the future are considered. The growing need for the study of minerals and rocks to expand innovative opportunities in various fields of science and technology is emphasised. The articlehighlights the challenges associated with teaching the geological component of the geography curriculum and the "I Explore the World" course in secondary schools, including the lack of specialised courses, insufficient teacher training, outdated teaching and learning resources, and limited opportunities for field research. An analysis of current research shows that digital technologies with AI can significantly change the approach to the formation of geological knowledge in students. The use of tools such as Google Lens, Google Earth, and Rock Identifier allows for virtual tours, automated mineral identification, and interactive learning. The article presents the results of field studies conducted at the summer schools of the National Centre 'Minor Academy of Sciences of Ukraine', which demonstrate the effectiveness of integrating AI into the educational process. The proposed methods include the use of mobile applications for identifying minerals in the field, as well as geological quests with elements of multimedia and interactive interaction. The need to improve mineral recognition algorithms and further develop virtual reality technologies to improve the educational process is emphasised. The conclusions confirm that the integration of digital technologies and AI into geological education contributes to increasing students' interest, expanding access to educational materials, and making the learning process more engaging and effective. Further research is focused on the use of more complex educational simulations that will help improve geological education on a global scale.

Keywords: *geography; geology; minerals; artificial intelligence; geological education; mineral identification; Google Earth; Google Lens; Rock Identifier; STEM education; interactive learning.*

Statement of the problem. Geological knowledge, knowledge about minerals and mineral resources is crucial for understanding the distribution, formation and location of natural resources, without which the existence of human civilisation would be impossible. Technological advances have accelerated the growth in demand for mineral raw materials needed to support modern technologies such as electric vehicles, renewable energy and electronic devices, so the study of minerals and rocks can play a significant role in many professions of the future, including genetic engineering, design and marketing, and others.

For example, in the field of genetic engineering, minerals and rocks are used as sources of raw materials for creating genetically modified organisms. For example, rocks containing sulphur are used in the production of amino acids, which are the building blocks for proteins and are crucial for genetic engineering. In addition, minerals such as selenium and zinc are essential for maintaining healthy genetic material and protecting cells from damage, making them valuable for genetic engineering [1].

Geological knowledge is also important for the design industry, which often draws inspiration from the natural world, in particular from minerals and rocks. The unique properties of minerals and rocks, such as their colours, textures and patterns, can be used to create innovative design solutions, from jewellery to furniture. Moreover, some minerals are valued for their rarity, making them highly sought-after materials in the design of luxury goods [2].

In marketing, minerals and rocks play an important role in creating effective advertising campaigns. For example, mineral-based cosmetics can be positioned as natural and environmentally friendly, which attracts consumers looking for environmentally friendly products. Minerals and rocks can also be used to create a unique packaging design that stands out on store shelves and attracts consumers' attention [3].

Another aspect that contributes to the interest in studying gemstones is related to their unique physical, chemical and geological properties. For students, this may be their first encounter with more complex scientific concepts such as crystal structures, mineralogy and the geological processes that lead to the formation of these materials. This approach can encourage young people to study STEM disciplines (science, technology, engineering, mathematics) [4]. In this context, AI can be used to classify and analyse gemstones based on their characteristics, such as colour, transparency or internal inclusions, using machine learning algorithms to automatically recognise minerals. Such technologies can also aid scientific research by creating models of how minerals form in different geological environments.

Developing skills in the study of stones is relevant to education in Ukraine, which is rich in mineral resources, many of which are unique, making the country an important part of the global gemstone market. The geological study of rocks and minerals can stimulate economic development and attract investment in the mining and processing industries.

The study of minerals and rocks is also important for a range of future careers, from genetic engineering to design and marketing. By understanding the unique properties and potential applications of minerals and rocks, professionals can create innovative solutions to meet the demands of the modern world.

Understanding the geology of an area is also necessary to identify potential hazards such as earthquakes, volcanic eruptions and landslides, and to develop strategies to mitigate their effects. A very important aspect is the application of geological knowledge to achieve the goals of sustainable development: while continuing to exploit the resources of our planet, humanity must balance economic development with environmental sustainability [5].

Practical experience shows that there are a number of problems in teaching elements of geology and mineralogy in secondary schools [6]. These include limited integration into the curriculum, marginalisation and integration with general environmental science [7]. This lack of specialised courses in geology and mineralogy makes it difficult for students to develop a comprehensive understanding of geosystems and geoscience. Another important aspect affecting the quality of geological education in secondary schools is the lack of teacher training in geology and mineralogy, resulting in outdated or superficial teaching. In addition, schools often lack adequate laboratory equipment for practical mineral analysis and fieldwork. There are also limited opportunities to gain practical experience through field trips, which are crucial to geological learning but are often expensive or logistically difficult and therefore rare. This leads to a decline in student interest in geology and mineralogy, with a consequent lack of awareness of career prospects in geology and related professions.

Addressing these challenges requires policy changes, better teacher training and investment in resources and technology. However, modern tools such as GIS (Geographic Information Systems), remote sensing and 3D modelling, as well as virtual laboratories and mineral analysis simulators, could more quickly fill the resource gaps.

Analysis of recent research and publications. Modern learning technologies based on artificial intelligence (AI) are now widely used in geosciences, geology education and ecology, which is confirmed by the growing number of scientific publications [8; 9]. For example, according to Dimensions AI, an analytical platform that allows receiving and analysing scientific publications, patents, grants, etc. according to the keywords "artificial intelligence", "geology", "ecology", "geography", "STEM", "Google Lens", there is a clear average increase in interest in this type of research *(Fig. 1)*.

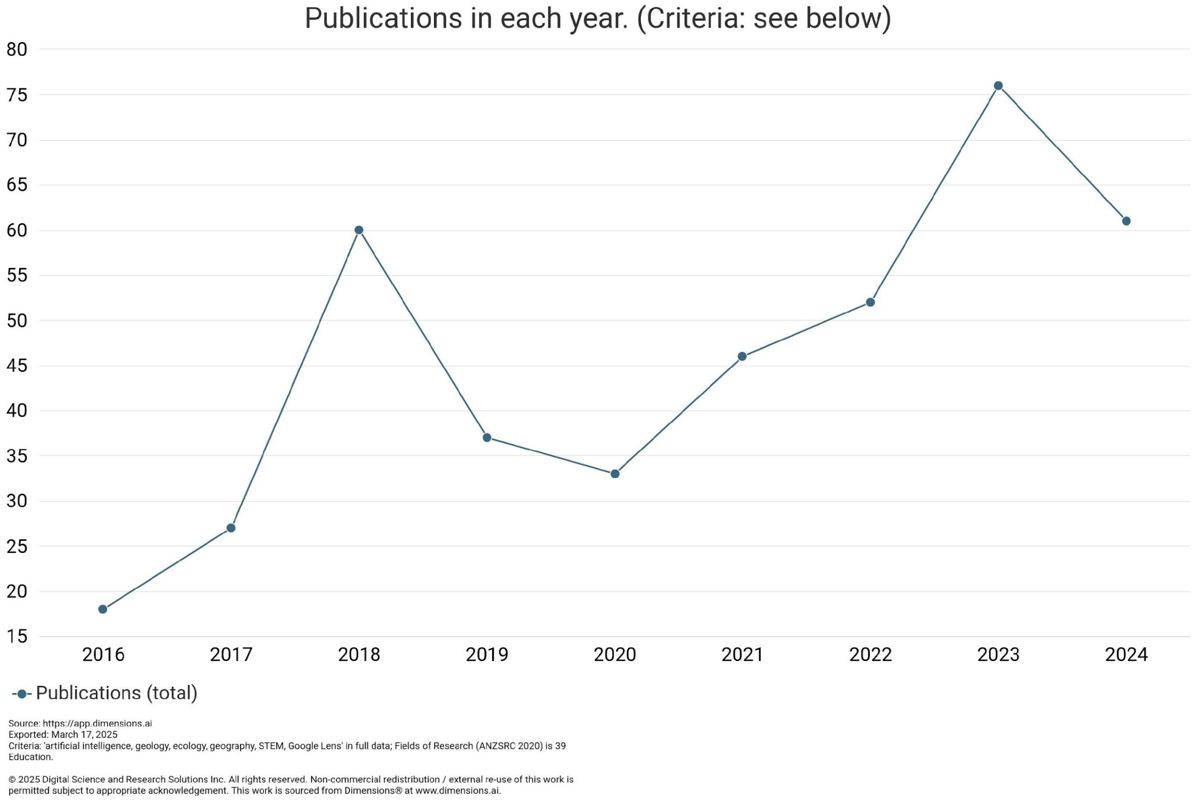

Fig. 1. Dynamics of the number of scientific publications in 2016–2024 (according to https://www.dimensions.ai/)

People of all ages have always been interested in gemstones and there are several reasons for this. First and foremost, it is the aesthetic appeal of a wide range of colours, unique textures and rare properties that sparks an interest in nature and science in general. AI, virtual and augmented reality can enhance this by providing 3D visualisations of rocks, simulations of their formation or analysis of their properties at a level beyond human perception, allowing you to 'touch' the processes of creation and evolution of minerals, making learning even more exciting [10–12].

Interest in the study of stones is fuelled by their symbolism and historical value. In many cultures, stones are associated with status, wealth and power, which stimulates interest on a social level [13]. For example, gemstones have been used to make jewellery, religious symbols and even weapons. Their history is closely linked to human civilisations, and studying this aspect can be a great tool for engaging students in history and culture through geology [14–16]. In this case, AI can be used to analyse the properties of rocks and their possible origins, as well as to help create a historical context for each sample, combining different disciplines: from geology to history and cultural studies [17; 18].

In this context, the *Google Earth* application has proven to be a very good educational tool, providing unique opportunities to explore geography, history and ecology through interactive 3D maps and satellite images [19]. This application can be used to explore various interesting geological sites and deposits. Google Earth provides access to high-resolution satellite images of the Earth's surface, which can be used to study geological features and processes in detail, and allows users to view the topography of the Earth's surface in 3D, facilitating the visualisation of the shape and structure of different landforms. This can be particularly useful for studying objects such as mountains, open-cast mines and quarries, etc.

Google Lens [20] as an effective tool for learning, helping to quickly translate text, identify objects and get additional information for a deeper understanding of the learning material [21; 22]. Another popular application is *Rock Identifier* [23], which helps to identify rocks from a photo. It has tools for analysing rock texture, colour and composition, and includes an interactive database for comparing samples.

Unfortunately, despite the continuing interest in rocks and their fascinating properties, today's students have limited opportunities to explore mineral deposits with their own eyes. This is due to a number of factors, including epidemiological restrictions, military threats and the long distances to some deposits and geologically interesting places, such as the volcanic rocks of the Karadag Massif in the Crimea or the corundum deposits on the island of Madagascar. According to G. Liventseva and M. Krochak [24], many schoolchildren today are bored in geological museums, distracted by gadgets and uninterested in mineralogical exhibits. Modern geological museums have introduced interactive teaching methods, tasks, quizzes, contests and competitions [25]. An alternative to a physical visit to a museum or deposit can be a virtual tour specially created with the help of augmented reality, which has been well proven in the example of multi-view stereo photogrammetry [8], but the creation of such tools requires certain financial costs.

Among the free quality resources, practical experimentation is also important, as is the search for and critical analysis of information from different sources and perspectives, and with different qualities and statuses. The issues of multidisciplinarity and engagement with knowledge are key considerations for science and environmental curricula [24; 25].

Unfortunately, geosciences are rarely found in the scientific and educational literature and are only occasionally included in lists of popular science topics. Existing research shows that children in middle school (8 to 12 years old) have less interest in geoscience than children of the same age in secondary school (11 to 18 years old) [26].

A study conducted in 2018 with a small sample (17 children aged 6–7) showed that children are able to classify minerals based on the natural properties of colour, transparency and luminescence [27].

During the period of COVID-19, we developed methods for forming the basics of geological knowledge at home [28].

Thus, the formation of geological knowledge in students of basic secondary education, which is inseparably connected with all natural sciences (physics, chemistry, geography and biology), is an important interdisciplinary pedagogical problem that can be solved in non-formal education with the use of artificial intelligence technologies.

The research goal. This article presents practical experiences in the development and use of geological literacy methods. These methods can be used in formal, non-formal and STEM education.

Research methodology. The relevance of the studied problem in the context of modern didactic approaches to the formation of basic geological knowledge using artificial intelligence technologies was analysed using the relevant scientific databases (Scopus, Web of Science, Google Scholar, Research Gate, Dimensions). Didactic developments of geological trainings and quests were developed in the STEM laboratory MAN Lab [28–32] of the National Centre “Junior Academy of Sciences of Ukraine” (NC JASU), tested during summer scientific schools in 2019–2022, at teacher trainings, seminars, conferences.

Results and discussion. A special feature was the provision of real gemstones (not of gem quality) for the children to study, which they were able to find with their own hands in one of the largest gemstone deposits in Europe, located near the town of Khoroshiv in the Zhytomyr region.

The aim of the project was to introduce children to the basic concepts and to develop practical skills of mineral classification in the field. The proposed methodology was developed during summer schools held by researchers of the Department of Creation of Educational and Thematic Knowledge Systems of the NC JASU in the cities of Chernivtsi, Uzhhorod, Kremenchuk, Kyiv, Kropyvnytskyi in the period from 2019 to 2022. Until now, students have not studied geology specifically and have mostly learned about minerals and rocks from school materials as part of the mandatory educational programmes for the school subjects I Explore the World [33] and Natural Sciences [34].

Before working directly with the stone material, the students had the opportunity to watch a training presentation in the form of a short lecture, which contained general information about minerals and rocks: characteristic properties, conditions of formation, distribution and types of simple diagnostics (Mohs hardness, line colour, adhesion), as well as interesting facts, etc. During this part of the event, the children got to know some samples of minerals and rocks from among those presented in virtual form. During this part of the event, the children got to know some samples of minerals and rocks from among those presented in virtual form during the presentation.

The next practical task was carried out by the children in groups of 4–6 people (depending on the total number of people in the audience). Each group received a set of 10 different samples of minerals, rocks and artificial materials (glass) found in the territory of the Volyn deposit *(Fig. 2)*, as well as common objects that could be used as diagnostic tools (a piece of glass with worked edges, a piece of vein quartz, a bronze coin and a steel knife, which was kept by the accompanying teacher and was available on request). Some of the teaching materials in the kit with good diagnostic properties were not of local origin, but were sometimes found in the area (charcoal, gypsum).

The task was to use the diagnostic materials and a mobile phone to identify and mark the name of each sample from the corresponding set. Each member of the team took turns to work on the samples independently, exchanging data with the others in the form of free communication. A special test was used as a data collection tool. Each of the children had to fill in a checklist and submit it to the experimenter for checking *(Fig. 3)*.

The data obtained were processed and summarised in a table *(Table 1)*, from which the following conclusions can be drawn.

From the above results we can conclude that the children perceived the pre-presented specific geological information well and actively used mobile applications (Google Lens and Rock Identifier) and reference materials (Wikipedia, materials in science

Fig. 2. An example of a set of samples for geological research during the summer schools of the NC JASU in 2019–2022: (1 – glass, 2, 3, 4 – topaz, 5 – citrine (quartz), 6 – rock crystal (quartz), 7 – gypsum, 8 – fluorite, 9 – morion (quartz), 10 – coal)

Task. Using your own observations, your smartphone and the internet, in particular Google Lens, try to identify the specimen provided, if you know where it was found.

No. of sample	***Name***	***Place of finding: Khoroshiv, Zhytomyr region***
Write down what you think is the likely name of the mineral or other substance you found.		

As a guide, the table below lists possible definitions.

Make a tick next to the options that you think are most likely.

phenakite		goethite		morion		zinwaldite	
topaz		rock crystal		opal		granite	
beryl		citrine		orthoclase		amber	
fluorite		smoky quartz		chalcedony		glass	

Fig. 3. Sample checklist of geological research in the summer schools of the NC JASU 2019–2022

Table 1

Data on the effectiveness of the developed methodology obtained during the summer schools of the NC JASU 2019–2022

Total questionnaire processed	194
Correct pre-determinations of all available samples	117
Error or no response	57
Correct versions of proposed options (bottom table)	137
Mobile applications and resources used	Google Lens, Rock Identifier Wikipedia, search services
Search keywords	Minerals of the Volyn deposit, gemstones, hardness, Mohs scale, bonding, museum of decorative and precious stones in Khoroshiv

textbooks, news sites), given their easy and quick accessibility and their trust in the scientific content. As a result, we obtained a fairly high percentage of correct definitions. An important factor is that working directly with real geological specimens, especially well-known gemstones, contributed to the general interest and allowed us to involve more students in the event. Problems arose due to the lack of practical experience of the participants and the less than perfect algorithm for identifying minerals in Google Lens. According to the experts from the Little Academy of Sciences, the algorithms for identifying plants are more perfect in this sense (from 55 %).

Another transdisciplinary methodological approach developed by the Department of Creation of Educational and Thematic Knowledge Systems of the NC JASU is geological quests. These intellectual competitions are developed using artificial intelligence, multimedia, real museum spaces and scientific institutions. They combine knowledge not only of natural sciences, but also of history, ecology, economics and other disciplines, so they can be considered a STEAM approach.

An example is the quest "Wonderful Find", which combines elements of the methodology described above, supplemented by the interaction of students with specialists and laboratory equipment of the National Centre of the Academy of Sciences of Ukraine, the National Museum of Natural History of the National Academy of Sciences of Ukraine and the State Gemological Centre of Ukraine and the Internet.

Conclusions. The use of digital technology and artificial intelligence has revolutionised the way children learn about geology and the identification of minerals and rocks. These cutting-edge tools have enabled students to interact with the subject in new ways, making the learning process easier, more interactive, engaging and fun. One of the key benefits of digital technologies and AI is their ability to mimic real-world environments. For example, interactive tools and applications (Google Earth, Google Lens, Rock Identifier, etc.) and virtual tours make geological education more accessible and inclusive, allowing students to explore geological formations and mineral deposits from the comfort of their own homes using 3D models and high-resolution images. This type of experiential learning is particularly effective in engaging learners who are under threat (war, pandemic restrictions, financial crises, etc.) and helps them to perceive and retain information. Thanks to the ability of machine learning algorithms to analyse large amounts of data and identify patterns and correlations that are difficult for humans to detect, this technology can be used to help students identify different types of minerals based on their physical properties, such as colour, hardness and density, or simply their appearance (rock identifier). By using AI tools, students can identify minerals quickly and accurately, improving their skills and confidence in the subject. In summary, the introduction of digital technologies and artificial intelligence is changing the way children learn about minerals and identify minerals and rocks. These tools make learning more engaging, interactive and accessible, helping to inspire the next generation of scientists and explorers.

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Пащенко Євген, кандидат економічних наук, старший науковий співробітник, відділ робототехнічних систем, Інститут прикладних систем управління НАН України;
науковий співробітник відділу створення навчально-тематичних систем знань, Національний центр «Мала академія наук України», м. Київ, Україна

Сліпухіна Ірина, докторка педагогічних наук, професорка, головна наукова співробітниця відділу створення навчально-тематичних систем знань, Національний центр «Мала академія наук України»;
головна наукова співробітниця відділу підтримки обдарованості, Інститут обдарованої дитини НАПН України, м. Київ, Україна

Чернецький Ігор, кандидат педагогічних наук, завідувач відділу створення навчально-тематичних систем знань, Національний центр «Мала академія наук України», м. Київ, Україна

STEM-ПІДХІД У НАВЧАННІ ГЕОГРАФІЇ: ВИКОРИСТАННЯ ШТУЧНОГО ІНТЕЛЕКТУ ДЛЯ ВИВЧЕННЯ МІНЕРАЛІВ І ГІРСЬКИХ ПОРІД

Анотація.

У статті розглянуто роль геологічних знань у сучасному суспільстві та їхній вплив на професії майбутнього. Підкреслено зростаючу потребу у вивченні мінералів і гірських порід для розширення інноваційних можливостей у різних галузях науки та техніки.

Висвітлено виклики, пов'язані з викладанням геологічного компонента в рамках програм із географії та курсі «Я досліджую світ» в середніх загальноосвітніх школах, зокрема відсутність спеціалізованих курсів, недостатній рівень підготовки вчителів, застарілі навчально-методичні ресурси та обмежені можливості для проведення польових досліджень. Аналіз сучасних досліджень показує, що цифрові технології з ШІ можуть суттєво змінити підхід до формування геологічних знань у здобувачів освіти. Використання таких інструментів, як Google Lens, Google Earth та Rock Identifier, дає змогу проводити віртуальні екскурсії, автоматизовану ідентифікацію мінералів та інтерактивне навчання. У статті представлено результати польових досліджень, проведених у літніх школах НЦ «Мала академія наук України», які демонструють ефективність інтеграції ШІ в освітній процес. Запропоновані методи включають використання мобільних додатків для ідентифікації мінералів у польових умовах, а також геологічні квести з елементами мультимедіа та інтерактивної взаємодії. Наголошено на необхідності вдосконалення алгоритмів розпізнавання мінералів та подальшого розвитку технологій віртуальної реальності для покращення освітнього процесу. Висновки підтверджують, що інтеграція цифрових технологій і ШІ в геологічну освіту сприяє підвищенню зацікавленості учнів, розширенню доступу до навчальних матеріалів, робить процес навчання більш захопливим та ефективним. Подальші дослідження орієнтовані на використання складніших навчальних симуляцій, які допоможуть покращити геологічну освіту в глобальному масштабі.

Ключові слова: *географія; геологія; корисні копалини; штучний інтелект; геологічна освіта; ідентифікація мінералів; Google Earth; Google Lens; Rock Identifier; STEM-освіта; інтерактивне навчання.*

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