



Application of Innovative Digital and Hybrid Tools in Geosciences and Mining Education

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<https://doi.org/10.29227/IM-2025-02-04-017>

Submission date: 20-11-2025 | Review date: 15-12-2025

Abstract

In the second decade of the 21st century, mining, especially coal, began to be perceived as an activity that negatively contributes to climate change, including global warming. This has caused the world to turn towards alternative energy sources, i.e. wind, solar, hydro or biomass energy. The European Union in particular has placed great emphasis on this aspect, which has resulted in mining, often unfairly, being perceived as something undesirable. As a result, educational mining faculties, including in Poland, are struggling with fewer and fewer potential pupils and students every year. The aim of the HoloGEM project, which is carried out in an international Polish-Turkish-Portuguese group, is to reverse this trend and make the recipients aware that mining is necessary to obtain all raw materials, without which it is impossible to produce many specialized equipment. However, in order to do this, it is also necessary to use modern, attractive forms of teaching. The HoloGEM project developed an innovative curriculum for educating the fundamentals of mining, covering issues in geology, underground mining, open-pit mining, mineral processing, and occupational health and safety. In addition to traditional content, in line with teaching guidelines in this area, VR materials, presentations with artificial intelligence were also developed, and the entire course was placed on an educational platform with Open Access. For each of the issues, sets of attractive forms of verification of the acquired knowledge have also been developed. The works use the latest solutions that are attractive to today's youth.

Keywords: HoloGEM, mining, education, students, VT, mineral resources

1. Introduction

Mining is one of the fundamental activities that enables the development and acquisition of mineral resources. Despite this, the industry's reputation among the general public, particularly in European countries, is generally poor. This is because the industry is primarily associated with coal mining, which is widely regarded as a source of environmental pollution, seismic issues and chronic respiratory and circulatory diseases. Furthermore, European Union countries are legally obliged to combat climate change. By 2050, they must transition to a climate-neutral economy with net-zero greenhouse gas emissions. This target was agreed at the European Council in December 2019, after which the European Commission launched the European Green Deal (Carvalho, 2017; Worlan-yo and Li, 2021). The commitment to achieving climate neutrality stems from the Paris Agreement, which all EU Member States have signed and ratified. Consequently, mining, particularly coal mining, has gained a reputation for being harmful and undesirable (Hirlekar et al., 2025). Meanwhile, Asian markets such as China and India are developing this branch of the economy and have not signed any environmental commitments in this area. Consequently, European fields of study related to mining are perceived as unattractive and offering no prospects for the future (Czaja, 2018; Jabulani, 2020; Majer and Nowak, 2011; Sobczyk, 2007).

Another issue is that the effects of the pandemic on education at different levels are still being felt. During the pandemic, faults in the educational system were exposed: teachers and students struggled to access adequate online education, and there was a mismatch between resources and needs. This

made it necessary to introduce new educational methods based on remote solutions (Adach-Pawelus et al., 2020; Bujara & Popczyk, 2016; Dipitsu, 2020; Fernandes et al., 2023; Miranda, 2023; Miranda et al., 2023; Newton et al., 2022; Popczyk, 2018; Razali & Nasri, 2023; Ukenova & Bekmanova, 2023; Yakovlev & Yakovleva, 2014).

Taking the above issues into account, an educational and didactic project entitled 'Holographic Integration for Geosciences Education and Mining' (HoloGEM) was submitted. The project aimed to change the perception of mining faculties as unattractive and unnecessary. Raising awareness of the importance of mining in the global economy will restore this type of education to its rightful position, making it more appealing to young people. The project was co-financed by the European Union under the Erasmus+ program, specifically under Key Action 2: Cooperation between organizations and institutions (KA220-VET) – Cooperation partnerships in vocational education and training. The project leader is AGH University of Science and Technology in Krakow, and the partners are institutions from three countries: Poland, Turkey and Portugal. To make the content more appealing, a course called 'Fundamentals of Mining' was developed, covering topics such as geology, underground coal mining, underground mining of ores (copper ore in particular), open-pit mining, mineral resource processing and occupational safety. A number of modern educational tools were proposed, including the use of artificial intelligence, virtual reality, augmented reality, educational games and internet tools based on platforms such as Kahoot. Classes conducted using modern tools can be partially online, and modern teaching techniques can be

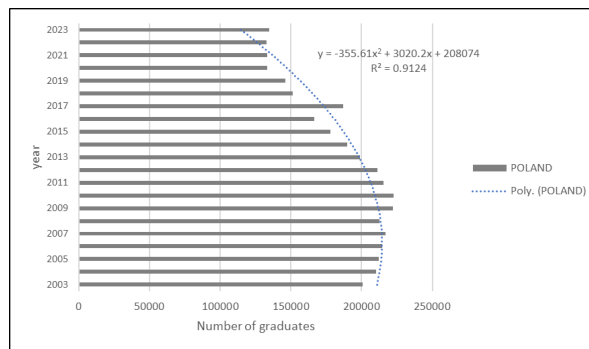


Fig. 1. Number of technical studies graduates in Poland during the period 2003 to 2023 (personal elaboration after <https://bdl.stat.gov.pl>)
 Rys. 1. Ilość absolwentów studiów technicznych w Polsce w latach 2003-2023 (opracowanie własne na podstawie <https://bdl.stat.gov.pl>)

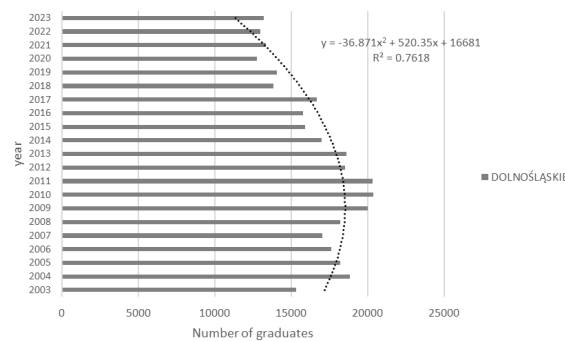


Fig. 2. Number of technical studies graduates in Dolnośląskie Voivodship during the period 2003 to 2023 (personal elaboration after: <https://bdl.stat.gov.pl>)
 Rys. 2. Ilość absolwentów studiów technicznych w Województwie Dolnośląskim w latach 2003-2023 (opracowanie własne na podstawie <https://bdl.stat.gov.pl>)

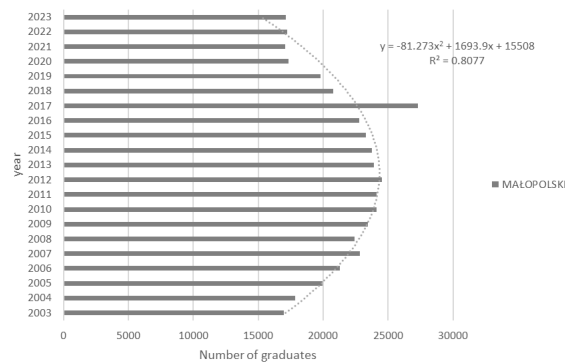


Fig. 3. Number of technical studies graduates in Małopolskie Voivodship during the period 2003 to 2023 (personal elaboration after: <https://bdl.stat.gov.pl>)
 Rys. 3. Ilość absolwentów studiów technicznych w Województwie Małopolskim w latach 2003-2023 (opracowanie własne na podstawie <https://bdl.stat.gov.pl>)

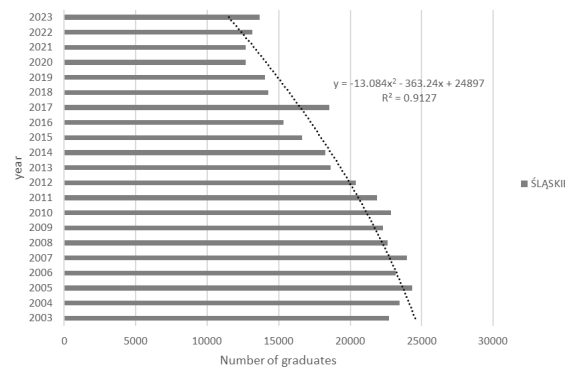


Fig. 4. Number of technical studies graduates in Śląskie Voivodship during the period 2003 to 2023 (personal elaboration after: <https://bdl.stat.gov.pl>)
 Rys. 4. Ilość absolwentów studiów technicznych w Województwie Śląskim w latach 2003-2023 (opracowanie własne na podstawie <https://bdl.stat.gov.pl>)

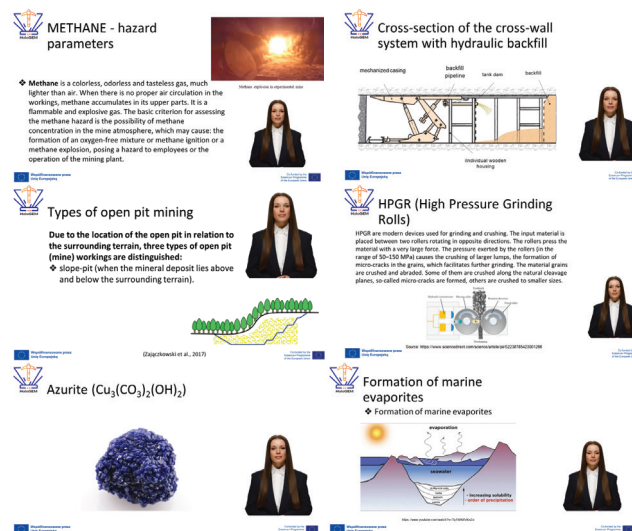


Fig. 5. Examples of using Artificial Intelligence in educational presentation (source: personal elaboration)
 Rys. 5. Przykłady zastosowania Sztucznej Inteligencji w prezentacjach edukacyjnych (źródło: opracowanie własne)

employed, such as the flipped classroom approach, teaching on social media, case study analysis and educational gaming (Bado, 2022; Davis et al., 2018; Niedoba et al., 2024; Safapour et al., 2019). This can also be achieved by using devices such as smartphones (Awedh et al., 2014). Introducing new content related to space or deep-sea mining could also be very appealing to students (Kleiv & Thornhill, 2022; Przylibski et al.).

Therefore, it is essential to develop a hybrid digital curriculum that offers innovative resources to assist with the integration and stability of traditional and digital teaching and learning methods (Alkhatlan & Kalita, 2018; Lindin et al., 2023; Létourneau et al., 2025; Yang & Zhang, 2019). Furthermore, the HoloGEM project aims to develop well-defined toolkits to provide teachers with educational resources and guides for e-learning and classroom teaching. The hybrid curriculum will incorporate the project's results to provide a comprehensive teaching and learning experience. This will support teachers, school leaders, and other teaching professionals, while addressing digital transformation through the development of digital readiness, flexibility, and capability. The project mainly targets vocational training in science and engineering, with a focus on mining and geosciences. Accordingly, the project aims to promote interest in and excellence in science, technology and engineering while presenting simulation tools and innovative teaching and learning practices (Erarslan & Şahbaz, 2024; Niedoba et al., 2024; 2025).

2. Mining education in Poland – current status

Between 2010 and 2015, there were a high number of pupils in schools and students in mining faculties in Poland. For example, the Faculty of Mining and Geoenvironment (now the Faculty of Civil Engineering and Resource Management) at AGH University in Krakow had around 200 students on mining-related courses each year. Currently, these numbers are much lower, and despite being recognized for their substantive level, e.g. according to the 'Perspektywy' ranking (<https://2025.ranking.perspektywy.pl>), these majors attract a small number of candidates every year. A similar trend can be observed at the other two institutions that educate people in mining: the Wrocław University of Science and Technolo-

gy and the Silesian University of Technology. The prospect of abandoning coal energy in the European Union is probably not conducive to increasing recruitment, but mining is identified only with hard coal in the consciousness of the average Polish resident. People also do not realize that coal can come in many different forms and that only one of these is steam coal, which is used directly for energy production. Coking coal is a rare earth element, while anthracite is used in the production of steel, for example. This raw material is also used by the chemical and sugar industries, as well as the rubber industry. In addition, anthracite is used in drinking water purification systems. It should also be noted that graphite and diamonds are forms of carbon.

In Poland, however, coal deposits are mainly hard coal, or steam coal. JSW S.A. mines coking coal, but running the company's operations is also problematic from an economic perspective. Lignite mining is also becoming increasingly expensive, primarily due to the costs of CO₂ emissions and the need for modernization. Furthermore, it is a highly carbon-intensive fuel, posing serious environmental and climate change concerns. Nevertheless, it should be noted that this coal can be used in the chemical industry for producing liquid fuels and fertilizers, for example.

The decreasing number of pupils and students in mining schools is also influenced by the demographic decline in Europe, including in Poland (<https://bd1.stat.gov.pl/>). This is clearly visible in the analysis of the number of graduates. Figure 1 illustrates the trend in changes to the number of technical graduates in Poland between 2003 and 2023. The best fitted one is polynomial function. Around 2010, the number of graduates in these subjects reached its peak. At that time, mining studies were still very popular and young people saw them as an opportunity to secure a well-paid job and a career as a mining engineer. However, the following years brought a change, causing a significant decrease in the number of technical study graduates. This situation was influenced not only by demographic decline, but also by the education reform which resulted in less emphasis being placed on science subjects in schools. This led to a lower level of primary and secondary school graduates, directly affecting their willingness to undertake the challenges involved

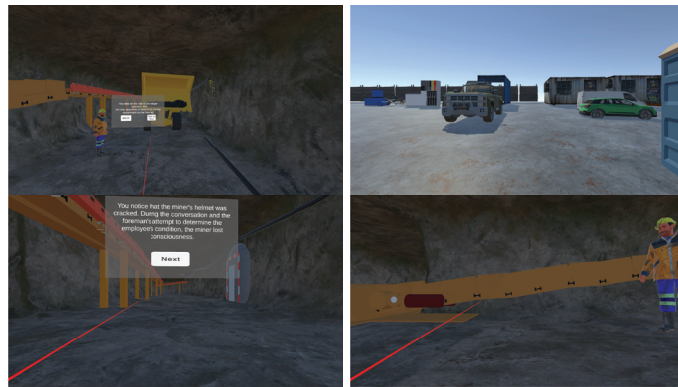


Fig. 6. Examples of the application of VR in an educational mining project (source: personal elaboration)
 Rys. 6. Przykłady zastosowania VR w projekcie edukacyjnym dotyczącym górnictwa (źródło: opracowanie własne)



Fig. 7. Images from the educational game in the field of Geology, made as part of the HoloGEM project (source: personal elaboration)
 Rys. 7. Obrazy z gry edukacyjnej z dziedziny Geologii, wykonanej jako część projektu HoloGEM (źródło: opracowanie własne)

in acquiring technical knowledge. Conversely, faculties related to sociology and psychology gained popularity, despite not guaranteeing well-paid employment.

Figures 2–4 present a similar analysis, but carried out for three voivodeships: Lower Silesia, Lesser Poland and Silesia, i.e. regions where centers (secondary schools and universities) that educate mining faculty students are located. Looking at the analysis of the number of technical studies graduates, a similar trend can be seen to that observed for Poland as a whole. The Silesian Voivodeship in particular has a very similar trend in the number of technical study graduates as Poland as a whole. For all considered voivodships, it is noted that the polynomial equation best describes the trend of variability. This is because, for example for Malopolskie when considering the period 2003–2023 there was recorded the highest number of graduates of technical studies in 2017. Therefore, it can be said that in the case of this voivodship the demographic decline has caused a delayed downward trend in the number of technical study graduates. However, this is also related to the wide range of technical studies available in Krakow. In addition to demographic decline, the following reasons should also be mentioned:

- Decline in interest in technical studies;
- The difficulty of the subject matter and the need for sufficient scientific skills.
- Willingness to take up paid work immediately after graduation.
- The pandemic period from 2019 to 2022.

Curriculum changes in primary and secondary schools have also resulted in a reduction in the emphasis on science.

Taking the above facts into account, what image of mining should we present to candidates for mining schools and

related fields of study? How can we convince them to perceive mining differently? In short, they need to be encouraged to think of the metallic heart of a sustainable future, which beats slowly and irregularly because there are no hands to keep it alive. This is what's at stake when there's a shortage of mining engineers – the professionals who understand the depths of the Earth and bring its minerals to the surface to power our smart cities, electric cars and recycling systems for future generations. Today, few have the courage to choose this path. The effect? A talent shortage that threatens every stage, from planning to overseeing mines on a planet hungry for lithium, copper and rare earths. Without these experts and their technical teams, the task becomes almost impossible.

- Discovering new deposits is crucial in a market where demand is growing rapidly.
- Implementing sustainable mining practices that respect the land that feeds us.
- Implementing advanced technologies, such as underground robots and sensors that can analyze rock formations.
- Reducing environmental and landscape impacts by transforming dust and waste into new opportunities and renaturing exploration areas.
- Recycling household appliances, smartphones, computers, and batteries in an urban mining project that returns metals to the production cycle.
- Compliance with complex regulations and engagement with communities, NGOs and governments, because community licenses are as important as legal licenses.

The future requires engineers with a new vision: those who are trained in mining as well as in environmental issues,

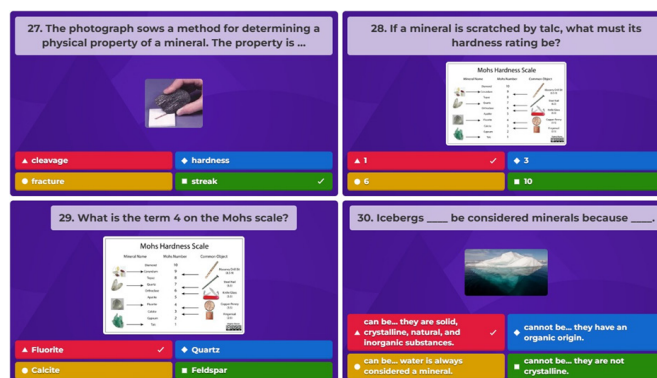


Fig. 8 Examples of Kahoot solutions for Geology (source: personal elaboration)
 Rys. 8. Przykłady zastosowania Kahoot w Geologii (źródło: opracowanie własne)

digitalization and the circular economy. The mining engineer of the 21st century does more than wield virtual pickaxes; they conduct scientific research, negotiate with nature, and commit to mining without devastation. After all, he is more than just a technician. They are agents of change and leaders of a civilization that is reinventing itself amidst rock and metal, responsibility and progress.

However, to achieve this, appropriate educational tools must be used that will attract potential students of mining sciences. These tools have been applied to each department included in the 'Mining Fundamentals' course as a result of the HoloGEM project.

3. Proposed improvements

3.1. Artificial intelligence

Artificial intelligence is undoubtedly one of the solutions used in education today. The use of various AI-powered websites has made different types of knowledge more accessible, but this is often indiscriminately accepted. AI learns using a methodology similar to that of algorithms based on so-called 'black box' methods. By associating facts, it looks for the optimum solution, but it does not necessarily have access to enough data to achieve this (Liang et al., 2024; Létourneau et al., 2025; López-Meneses, 2025).

In the HoloGEM project, we proposed combining artificial intelligence with verified, real-world news. E-books have been developed for each of the topics proposed in the 'Fundamentals of Mining' course, i.e. the sections on Geology, Underground Mining (Ore and Coal), Open-pit Mining, Processing of Mineral Resources, and Occupational Safety. This collection of information covers the basic scope of the above-mentioned sections for people with no experience or knowledge in these fields. The developed content will be available in electronic form on the HoloGEM project website and will be presented in four languages: English, Polish, Turkish and Portuguese. However, the difference from traditional PDF or PowerPoint presentations is the use of an artificial intelligence algorithm in the form of a talking avatar. This feature highlights the most important information from the content discussed on individual slides of the presentation. In total, 16 presentations were produced in four language versions. Figure 5 shows sample screenshots of selected presentations from selected sections. These were created using the Elai.io software.

3.2. Virtual and augmented reality

Another attractive way to enhance the educational process is through the use of virtual reality (VR) technology (Scavarelli et al., 2021; Tan et al., 2022). With the right hardware and software, we can visualize any environment, including mines and industrial plants. It can be treated as a kind of game and adventure. High-quality equipment is necessary for an appropriate impression, but even with fewer resources, an attractive form of education can be offered to school and university students. Figure 6 shows examples of visualizations of mining environments (both underground and open-pit mines). Similar solutions were used in the submodule on processing mineral resources, where sample processing machines and equipment were scanned and transferred to the VR environment.

Figure 7 shows screens from a VR game, in which students must identify the correct mineral. Competition increases the attractiveness and thus the effectiveness of teaching issues related to geology and mining. Other VR applications dealing with occupational safety and other submodules of the course are also being developed.

It is also worth mentioning that augmented reality (AR) is a technology that allows digital information, such as text, images or animations, to be added to the real world. AR enhances the physical world with digital information while enabling you to continue interacting with it. This distinguishes it from virtual reality, which is related but very different. Using AR technology in teaching, especially in conjunction with VR, produces excellent results.

3.3. Educational toolkits

As well as learning new content, it is important to verify learning outcomes. This can be achieved through the use of modern IT tools. These can take the form of various types of quizzes, tests and answer sheets, or you can use solutions offered online. One such form is the Kahoot platform, where you can create various types of multiple-choice tests and logic games to test knowledge. You can also add a time limit for answering a given question, which will encourage competition between students and thus increase their desire to gain knowledge in a given field. Figure 8 shows examples of Kahoot screens with questions about geology.

Similar tests have been created for other submodules. Proposed tools that could be used for this purpose include Wooclap, Doodle, Wordwall and the STE(A)M methodology.

Other attractive presentation tools include video recordings with content visualisation and QR codes that facilitate access to the content discussed in a given submodule.

All of these solutions will be implemented as part of the HoloGEM project, either already have been or will be soon.

4. Conclusions

Mining is and will continue to be necessary worldwide. Without it, it is impossible to develop technology, and thus impossible to develop the whole world. Therefore, the idea that the world can do without mining is unrealistic. Efforts should be made to improve extraction, processing and use technology, in economic and technological terms, to reduce the industry's adverse impact on people and the natural environment as much as possible. However, the approach to mining needs to change, particularly with regard to educating young people. Specialists in this field are needed now and

in the future, but the negative image of mining in the media means there are few new graduates willing to take on this hard and responsible work. The result may be not only a lower quality of mining products or uneconomical production activities, but also a direct threat to the health and lives of people working in mines.

By using modern educational solutions, more potential mining engineers will find their future in this industry, ensuring our development and the safety of miners.

Acknowledgement

The article is the result of the realization of the project Holographic Integration for Geosciences Education and Mining (HoloGEM, no. 2022-1-PL01-KA220-VET-000089946)



Co-funded by
the European Union

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Zastosowanie innowacyjnych cyfrowych i hybrydowych narzędzi edukacyjnych w naukach o ziemi i górnictwie

W drugiej dekadzie XXI wieku górnictwo, zwłaszcza węglowe, zaczęło być postrzegane jako działalność przyczyniająca się negatywnie do zmian klimatycznych, w tym globalnego ocieplenia. Spowodowało to, że świat zwrócił się w kierunku alternatywnych źródeł energii, tj. energia wiatrowa, słoneczna, wodna, czy energia z biomasy. Zwłaszcza Unia Europejska położyła na ten aspekt duży nacisk co spowodowało, że górnictwo, często niesprawiedliwie, postrzega się jako coś niepożądanego. Skutkiem tego, edukacyjne kierunki górnicze, w tym w Polsce, z roku na rok borykają się z coraz mniejszą ilością potencjalnych uczniów i studentów. Celem projektu HoloGEM, który jest realizowany w międzynarodowym gronie polsko-turecko-portugalskim jest odwrócenie tego trendu i uzmysłowienie odbiorcom, że górnictwo jest konieczne do uzyskiwania wszelkich surowców, bez których niemożliwa jest produkcja wielu specjalistycznych urządzeń. Aby tego dokonać trzeba jednak zastosować także nowoczesne, atrakcyjne formy nauczania. W ramach projektu HoloGEM opracowano nowatorski program edukacji podstaw górnictwa, obejmujący zagadnienia z geologii, górnictwa podziemnego, górnictwa odkrywkowego, przeróbki surowców mineralnych oraz bezpieczeństwa i higieny pracy. Oprócz tradycyjnych treści, zgodnych z wytycznymi nauczania w tym zakresie, opracowano także materiały VR, prezentacje z udziałem sztucznej inteligencji a całość kursu umieszczono na platformie edukacyjnej z dostępem Open Access. Do każdego z zagadnień opracowano także zestawy atrakcyjnych form weryfikacji pozyskanej wiedzy. W pracach zastosowano najnowsze rozwiązania, które są atrakcyjne dla współczesnej młodzieży.

Słowa kluczowe: *HoloGEM, górnictwo, edukacja, studenci, VR, surowce mineralne*