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Innovation in Geothermal Energy Education

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ABSTRACT

Geothermal energy-themed projects are multidisciplinary and involve multi-disciplinary expertise in both earth sciences and surface engineering. In geothermal projects, specialists work together, and sometimes teams working in subsurface and surface engineering have little knowledge of each other's work areas unless they have experience in the field. However, in both main fields, providing information about the fundamentals of the other field during education or related courses will facilitate students to look at systems from a holistic perspective. In addition, in geothermal energy projects in the sector, many data are taken from both underground and surface, and it becomes more difficult to use these data in a meaningful way. For this purpose, the data provided in geothermal, providing information about the working conditions of the system, making useful predictions is now a part of the learning will be able to increase the number and competence of people who will work in this field. Within the scope of this study, innovative perspectives in geothermal education will be shared.

1 INTRODUCTION

Geothermal energy is one of the important renewable energy sources; however, it is still utilized far below its potential, both in electricity generation and in direct applications. Geothermal resources, where traditional methods are still heavily used in energy production, can be re-evaluated with an innovative perspective as global energy investment policies change and financial support increases.

The development of geothermal energy projects is inherently multidisciplinary and requires seamless collaboration between experts in geology, geophysics, drilling engineering, geochemistry, mechanical engineering, energy systems engineering, process engineering, automation, and environmental sciences. Each of these fields requires deep expertise, but the success of geothermal projects depends not only on expertise in individual fields, but also on the ability of professionals to understand the fundamentals of each other's work. However, in practice, subsurface and surface engineering teams often work with limited knowledge of each other's workflows, assumptions, and constraints. Initially, a reservoir engineer or geochemist may have limited knowledge of surface facility processes, while a mechanical or energy systems engineer may lack sufficient knowledge of reservoir behavior, reinjection dynamics, or fluid chemistry. When multidisciplinary familiarity is lacking, teams may spend substantial time aligning concepts, interpreting terminology, and understanding each other’s decision-making frameworks. This can lead to inefficiencies, communication barriers, and, in some cases, suboptimal project outcomes. In large-scale geothermal developments, where reservoir performance, well integrity, thermodynamic cycle design, and surface equipment decisions are tightly interconnected, these gaps become particularly evident.

One contributing factor to these communication challenges is the way geothermal-related topics are traditionally taught. Earth sciences curricula emphasize reservoir geology, geophysical imaging, petrophysics, fluid–rock interactions, and geochemical characterization. In contrast, mechanical and energy engineering programs focus on thermodynamic cycles, heat exchangers, turbines, pumps, materials, automation, and process safety. While both perspectives are essential, students rarely encounter a curriculum that integrates these components into a unified system-level understanding of geothermal energy production. As geothermal projects become increasingly complex with hybrid power plants, flexible generation strategies, enhanced geothermal systems (EGS), district heating networks, and digital monitoring technologies, there is a growing need for a new educational model. Such a model must help students appreciate the full geothermal value chain, understand the interactions between subsurface and surface systems, and develop the communication and analytical skills needed for multidisciplinary collaboration.

This paper introduces a holistic geothermal education approach designed to address these gaps. The model incorporates integrated theoretical teaching, multidisciplinary team-based project work, real geothermal plant case studies, data analysis, prototype development, and direct interaction with national and international experts. By combining subsurface and surface engineering concepts in a unified learning environment, the

course aims to prepare students for the collaborative, data-driven, and innovation-focused nature of contemporary geothermal projects.

2. BACKROUND AND CURRENT CHALLENGES IN GEOTHERMAL EDUCATION

2.1 Traditional Education Limitations

Most geothermal-focused university programs emphasize either: earth sciences (reservoir geology, geochemistry, geophysics), or engineering and energy conversion (thermodynamics, surface plant design, drilling, production engineering).

While students gain depth within their fields, they often lack: Understanding of the entire geothermal value chain, exposure to operational workflows in real geothermal plants, awareness of data types collected in subsurface and surface systems, experience interacting with professionals from other engineering backgrounds. Pecen et al., support multi-discipliner approaches in geothermal education in their study. Elkarmoty et al. 2021 demonstrate the success of multidisciplinary education in geothermal energy through a pilot study conducted with several universities in Egypt while, Toth (2015) discusses the positive contribution of different disciplines to learning through e-learning cooperation in education in Hungary. Zarrouck (2017) emphasizes the decline in postdoctoral programs in the field of geothermal energy worldwide, noting the closure of some programs supported by UNESCO and UNDP in Italy and Japan and the decrease in financial support for postdoctoral students by companies.

Depending on the distribution and historical development of geothermal energy applications, geothermal energy-themed courses at universities are prominent in certain countries around the world. It is known that there are around 30 academic units and national geothermal associations worldwide (IGA, 2025). Courses on geothermal energy are offered within the departments of mechanical engineering, petroleum and natural gas & reservoir engineering, and geological engineering, particularly in regions with intensive geothermal applications such as the USA, Europe, and Türkiye. A preliminary scan of US university curricula suggests that only a limited number of institutions offer dedicated undergraduate courses or significant modules on geothermal energy or geo-energy engineering (e.g., Oregon Tech, University of Nevada Reno, Colorado School of Mines, New Mexico Tech, University of Oklahoma, Stanford, University of Utah). Even in these cases, courses are typically discipline-specific (mechanical, reservoir, or geoscience) rather than explicitly designed as integrated, multidisciplinary geothermal systems education.

While there are master's programs focused on geothermal or geo-energy in Europe (Friedrich-Alexander-Universität Erlangen–Nürnberg (FAU) & TU München, Bochum, Freiberg), some universities offer geothermal courses (such as the University of Stavanger and the University of Iceland). In master's-level courses, apart from FAU/TUM, a single disciplinary perspective generally dominates. In Türkiye, where various geothermal applications exist, reservoir engineering, geological engineering and mechanical engineering offer traditional training programs, while Energy Systems Engineering also offers courses on geothermal systems. The courses and education programs related to geothermal energy are available in Japan and China, but the number of courses directly at degree level, under the heading of ‘Geothermal Energy Systems’ within the engineering discipline, records to be limited. The University of Auckland (New Zealand) and the University of New South Wales (Australia) offer courses on geothermal Resources and their usage and geothermal energy technologies.

2.2 Increasing Complexity of Geothermal Data

Modern geothermal operations generate large, diverse datasets such as reservoir temperature and pressure logs, production and reinjection data, geochemical monitoring time series, plant operation metrics (power plant performance, pump loads, heat exchange efficiency etc.). Without foundational knowledge of both domains, students struggle to interpret these datasets or understand their relevance to overall system performance. The joint evaluation of these data with information obtained from underground sources necessitates the understanding of multi-layered data in order to ensure optimal energy production from above-ground mechanical systems based on the fluid coming from underground, to determine the status of equipment, to examine turbine performance, and to study changes in the behavior of each production and reinjection well during long-term production. This also highlights the importance of comprehensive education.

2.3 Global Trends Supporting Educational Innovation

Recent advances highlight the importance of multidisciplinary competences; EGS projects demand joint reservoir and mechanical engineering design while, hybrid geothermal systems (such as geothermal and solar) require collaboration between energy systems engineers and geochemists. Besides that, data-driven

geothermal applications (AI/ML, digital twins) require comprehensive data literacy and qualified experts to understand the performance problems and solve them in a short period to minimize energy losses in a system. These drivers justify the need for more holistic geothermal education model now.

3. CONCEPTUAL FRAMEWORK: HOLISTIC& MULTIDISCIPLINARY GEOTHERMAL EDUCATION

3.1 Holistic Learning

Holistic learning is an educational philosophy that views knowledge and human development not as separate parts, but as interconnected processes. By bringing together multiple disciplines, experiences, and perspectives, it aims to educate the individual holistically in intellectual, emotional, social, physical, and spiritual terms (Mahmoudi et al., 2012).

In a holistic approach, learning is not limited to acquiring facts or technical skills; instead, it emphasizes understanding relationships, systems, and contexts. Especially undergraduate students are encouraged to see how different fields are connected, such as how geology, chemistry, data science, and environmental policy interact within geothermal systems.

Holistic learning also values experiential and reflective learning: students learn by engaging directly with real-world problems through collaborative projects and self-reflection. The goal is to develop not only competence but also awareness, empathy, and a sense of responsibility towards the environment and society.

In the context of geothermal education, holistic learning means integrating the scientific, technological, environmental, and socio-economic dimensions of geothermal energy. It helps students understand the entire ecosystem, from geological processes to sustainable resource management, and encourages the integrative thinking and systems awareness necessary for the next generation of geothermal experts.

3.2 Multi-disciplinary and Project-Based Learning

Multidisciplinary learning involves students from geology, mechanical engineering, and other disciplines learning together in the same classroom. It involves creating projects, assigning team roles according to disciplines, and simulating “real geothermal team operations.” Project-based learning enables students to not only learn theory but also produce products/solutions, allowing teams to form that design solutions for field problems. In this context, periodic progress review meetings can facilitate critical thinking and design-oriented learning. While developing the project, conducting mock-up studies that express the basic operation of the system can improve understanding and produce a solid product.

4. CASE STUDY: IMPLEMENTATION OF A HOLISTIC AND MULTIDISCIPLINARY TEACHING MODEL IN A UNIVERSITY

This section presents a detailed case study of the holistic teaching approach implemented in an undergraduate and graduate geothermal energy course. The model integrates multi-disciplinary teamwork, project-based learning, real-world plant analysis, industry communication, data-driven evaluation, and prototype development. It aims to give students from various disciplines the systems-level thinking, applied engineering skills, and professional communication abilities needed in the geothermal industry.

4.1 Undergraduate Level: Multidisciplinary, Project-Based Geothermal Systems Course

The undergraduate elective course accepts students from a broad range of Engineering disciplines, including: energy systems, earthscience based, mechanical, mechatronics, industrial, computer, electrical&electrionics, civil and bioengineering. This diversity reflects the inherently multidisciplinary nature of geothermal projects, where subsurface experts, plant engineers, and data analysts must work collaboratively.

The course consists of two parallel components such as; theoretical foundation on geothermal systems, subsurface–surface interactions, plant operations, data-driven approaches in geothermal and a semester-long group project, in which students analyze and redesign a real geothermal facility.

4.2 Formation of Multidisciplinary Project Teams and Selection of Geothermal Projects

The first two weeks, students form project teams of 4–6 members based on the following criteria:

- Each team must include at least three different disciplines.

- Each team must include at least one Energy Systems Engineering student.
- A team leader is appointed to coordinate responsibilities.

This structure mirrors real geothermal project environments, where teams work across subfields with defined roles.

After determination of the groups each team selects a real geothermal-based project from Türkiye or around the world. These may include: electricity generation plants (ORC, flash, hybrid cycles), district heating/cooling systems, hybrid and combine systems such as; geothermal-solar power project or geothermal-green hydrogen production project.

Students are instructed to approach the project as if it were being redeveloped from scratch. This requires a multi-layered analysis covering both subsurface and surface processes.

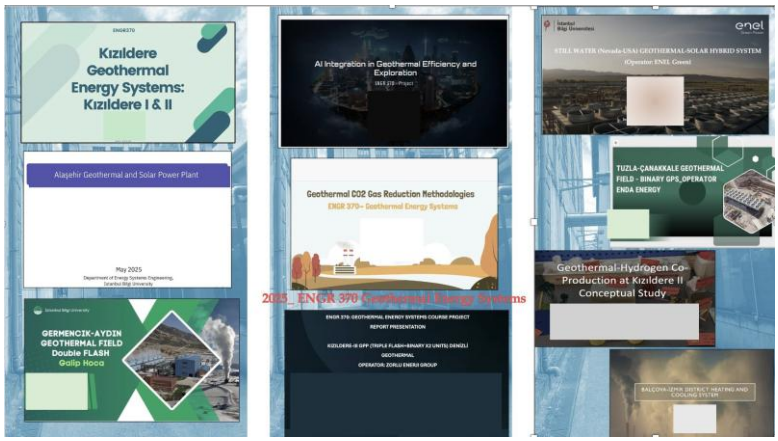


Figure.1 Some of the student project studies in 2025

4.3 Structured Project Framework

The students prepare a comprehensive project report following a structured framework provided at the start of the course. This framework consists of five main components like geothermal project development in real.

Subsurface Analysis (Geoscience Foundations): Geological setting and reservoir characteristics, number and type of wells, reservoir parameters and reinjection strategy, geochemical properties of the fluid (major ions, variability, scaling potential), surface plant and process engineering, description of plant type and operating and working principles, Identification and explanation of major equipment, drawing of a Process Flow Diagram (PFD) using AutoCAD.

- *Data Processing and Performance Evaluation*

Students may use Python to; retrieve yearly production values, calculate the plant's capacity factor, visualize production trends, interpret performance changes and discuss potential causes

This component develops data literacy and analytical skills increasingly required in modern geothermal operations.

- *Environmental Impact Assessment*

Evaluation of emissions (CO_2, non-condensable gases), thermal pollution and surface-water impacts, performance of e-injection application in the system.

- *Results, Recommendations, and Possible Future Work*

Each team proposes its own solutions, such as; efficiency improvements, equipment upgrades, AI-based monitoring and optimization tools, CO_2 storage/ utilization pathways, Integration of emerging technologies (e.g., digital twins, advanced materials (based on their capabilities).

4.4 Industry Contact Requirement

One of the most innovative and impactful elements of the course is the requirement for direct communication with sector professional during their education.

Students are asked to contact: engineers currently working at the selected facility, supervisors from their previous internships, international plant operators (through LinkedIn or e-mail). If communication barriers arise (e.g., time zones, unavailable staff), the instructor provides additional support or alternative contacts.

This requirement teaches students how to obtain missing operational information—an essential skill in real project development.

4.5 Discipline-Oriented Task Allocation

Task distribution within the teams is aligned with students' academic backgrounds: **computer engineers:** data analysis, AI/ML prediction models, **bioengineers:** CO_2 conversion, mitigation technologies, **mechanical engineers:** equipment design, heat exchangers, pump characteristics, **energy engineers:** cycle efficiency, thermodynamic analysis, drawings, **geoscience students:** reservoir interpretation, subsurface conceptual modeling

This approach ensures a natural interdisciplinary workflow and enhances collaborative learning.

4.6 Final Deliverables and Assessment

At the end of the semester, each team submits: A comprehensive written project report, aphysical model of the geothermal plant, showing major components and flow paths, a presentation summarizing their analysis and recommendations These deliverables are evaluated along with a midterm and final exam, forming a balanced grading structure that combines theoretical understanding and applied project work.

4.7 Industry Contact Requirement and Expert Engagement

One of the most innovative and impactful elements of the course is the requirement for direct communication with sector professionals. Students are asked to contact engineers currently working at the selected facility, supervisors from their previous internships, or international plant operators through platforms such as LinkedIn or e-mail. When communication barriers arise such as; unavailable staff or international time-zone limitations the instructor provides additional support or alternative contacts. This requirement teaches students how to obtain missing operational information, an essential skill in real project development.

In addition to direct industry contact, the course incorporates expert seminars delivered by national and international specialists from various geothermal subfields. Throughout the semester, invited experts—working in reservoir engineering, geochemistry, drilling operations, power plant design, or geothermal project development—participate either face-to-face or online. These sessions not only expose students to diverse professional experiences but also provide insight into Horizon 2020 and Horizon Europe–funded geothermal research and innovation projects. This international engagement significantly broadens students' perspectives and enhances the global and interdisciplinary character of the course.

5. Conclusion

This study presents a holistic and multi-disciplinary approach to geothermal energy education that integrates subsurface sciences, surface engineering, environmental evaluation, and data analysis into a single project-based learning framework Unlike traditional curricula such as geology, reservoir engineering, or mechanical engineering, this model brings together students from different disciplines to analyze real geothermal power plants, develop process diagrams, perform data-driven assessments, create physical prototypes, and communicate directly with industry experts. Initial results show that students have gained a stronger system-level understanding of geothermal operations and significantly improved their interdisciplinary communication skills. The findings emphasize the need for more integrated, application-oriented geothermal education globally and show that such holistic models can better prepare future professionals for the complex and interconnected nature of the geothermal sector.

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