Report on Testing Pedagogical Tools

Summary report   Intellectual Output 9

August 18, 2022   Geo3En IO9

1 Introduction

Innovative pedagogical tools include site visits, baseline courses and entrepreneurship skills in the field of geothermal engineering.

Site visits (IO6) are conceived for students to investigate geothermal reservoir analogues on sedimentary basins, volcanic areas and orogen foreland domains to understand and evaluate the possibility of using them in the production of useful energy (heat, electricity); visit operating geothermal facilities (power plants, heating plants) and discuss with sites owners operating at various exploitable enthalpy conditions to get an insight on plant equipment, operating parameters, efficiency and energy potential of production system; test reservoir rocks petrophysical properties in the laboratory.

The baseline courses (IO7) are carefully created with the idea that students get all the necessary knowledge and competences in geothermal energy. The courses are divided into four large groups for which four partners in the project are responsible. They cover general subjects such as the concept of geological reservoir, geology engineering, borehole types, drilling, fluid rock interaction, heat transfer in deep geological structures, heat extraction to the surface, overview of electrical power system, geothermal power plants (types, principle of operation, efficiency), environmental impact assessment, management and financing.

Developing a course on entrepreneurship in geothermal business (IO8) is an important milestone in creating the curriculum. The perquisite for creating a successful business that covers entrepreneurship and innovation is the knowledge of the scientific and technical aspects presented in IO6 and IO7. Technology does not exist in isolation but is dependent upon natural sciences, technical feasibility and market need. The course includes development of a business, design and implementation plans, market analysis, expected sales curve, plan for market implementation, technical feasibility, development of a prototype, intellectual property and patent rights, calculations of financial need, financing, income, cost, profitability and evaluation of business idea.

The innovative pedagogical tools were continuously tested during the intensive study programmes in the field and online lectures. The final student project summarized the knowledge the students had acquired and applied it to the complex problem of techno-economic analysis of the geothermal project at the location of Upper Rhine Graben.

2 Evaluation of innovative pedagogical tools

The (continuous) evaluation of innovative pedagogical tools was carried out in several ways:

1. discussion and exercises after the lectures,
2. quizzes after the lectures,
3. group discussions and presentations after the field trips,
4. conducting a survey,
5. student projects.

Testing and monitoring of students' work, the quality of teaching materials, the organization of field trips and visits to technical facilities took place continuously throughout the ISP. Given that this is the first time such a complex project has been implemented, it was crucial that students, as well as coordinators, i.e. teachers, openly comment on their impressions, whether they are positive or negative. In this sense, the whole process was very dynamic because all observed problems were solved on the spot so that the final result, the quality transfer of knowledge to students, was as good as possible. It was therefore important to create a strong and positive relationship between teachers and students, but also between students themselves, regardless of their prior knowledge, be it more scientific or engineering. Testing, monitoring and review are thus an integral part of such a multidisciplinary international project.

2.1 Discussion and exercises after the lectures

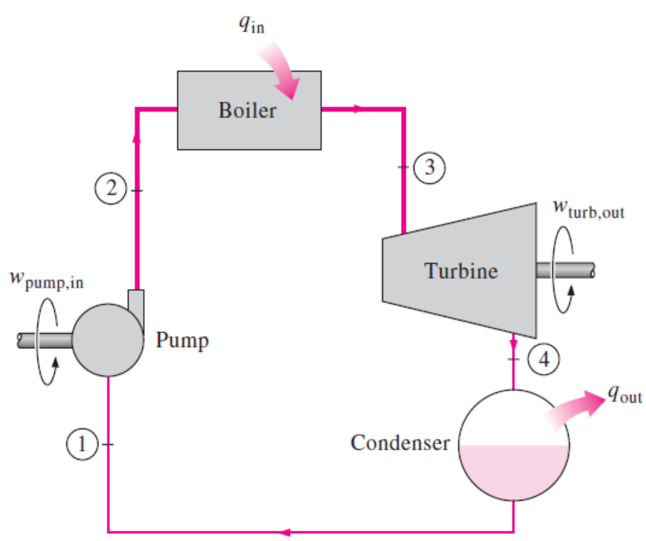
The idea of group discussions was introduced by University of Darmstadt. Considering the complexity of the material (geothermal systems under different reservoir conditions, petrophysics, fluid-rock interaction and heat transfer, subsurface engineering, geothermal potential, etc.) it was necessary to enable the students to understand the material in such a way that the most important elements of the lecture could be discussed and analyzed. Students with the background in the mechanical and electrical engineering needed more clarification and examples because they encountered this topic for the first time. Of course, the focus of discussions was on the competencies that every student must acquire. The discussions are in a free format and are not necessarily related to the teacher explaining the material to the student. They are completely open and the objective is that other students get involved and actively participate. In this case, the multidisciplinarity and prior knowledge of students play an important role, creating cohesion within the group where students transfer knowledge to each other, and the teacher acts as a moderator who directs the course of the discussion in order to keep a focus on the competence requirements. In such a free discussion, it is very easy to see the advantages and disadvantages of lectures, whether they are thorough, whether they meet the given criteria, whether they are too simple or too complicated, whether they provide too much or too little information. The result of the discussion is clear, to improve the existing teaching materials so that all students, regardless of prior knowledge, acquire all the expected competencies. Students reacted very positively to this way of evaluation, i.e. interaction.

A similar approach was taken by UniLaSalle University, which combined live lectures and online presentations, where one group of students was live in the classroom, and the other was virtual. These lectures included 3D graphic outcrop visualization (photogrammetric techniques, overprinting deformation phases and strain gradients), which represented an additional challenge for students and lecturers. 2D and 3D visualization is crucial in geological research, and that is why a lot of emphasis was placed on it, especially during the field work.

Solving numerical examples is an extremely important method for acquiring knowledge/competences in engineering. Not only for the reason of clarifying the theoretical background, but also because the numerical parameters of the plant are crucial in understanding the nature of the source of useful energy. Only on the basis of the description of the mode of operation, heat extraction, flow of the working medium and knowledge of thermodynamic cycles, it is not possible to conclude what is the actual output from the thermal power plant. It could very easily be deduced that geothermal power plants produce the same or similar amount of electricity as fossil fuel thermal power plants or nuclear power plants, although this amount is many times smaller, which results from the physical drawbacks, i.e. the energy density. To test the pedagogical tools and to enable students to acquire engineering competencies, especially the students with more scientific background, a simple numerical examples were solved after each lecture about the power plant operation. The examples were reduced to solving linear algebraic equations of energy conservation, and complicated differential equations were avoided so that the physical description remained clear and students understood the technical principles.

One such example is given here:

A 15 MWe binary geothermal power plant in Costa Rica uses organic Rankine cycle in which the specific enthalpy at the turbine inlet is 530 kJ/kg, at the turbine outlet 453 kJ/kg, at the condenser outlet 15.2 kJ/kg and at the outlet from the feedwater pump 18.2 kJ/kg. Calculate thermal efficiency and mass flow rate of the working fluid.



$$\eta_{th} = \frac{w_t - w_p}{q_{in}} = \frac{h_3 - h_4 - (h_2 - h_1)}{h_3 - h_2} = \frac{530 - 453 - (18.2 - 15.2)}{530 - 18.2} = 0.145$$

$$\dot{m} = \frac{P}{w_t} = \frac{15000}{530 - 453} = 195 kg / s$$

In this simple example, the energy balance in the power plant: the heat source in the geothermal reservoir, the heat sink in the condenser, and the work output in the turbine are shown and quantified. The thermal efficiency is the ratio of the work output to the internal energy input and is relatively small in a geothermal power plant compared to classic thermal power plants where it is greater than 30%. The flow rate is rather high for such a small plant meaning that the facility is very large, its pipings, components, valves, heat exchangers, power plant area, etc. Only through a theoretical presentation of the operation of the power plant it would not be possible to reach these insights, and students can more easily draw conclusions and get a clear idea of engineering principles.

2.2 Quizzes after the lectures

Short quizzes after the lectures were introduced by Reykjavík University. It is a fast and efficient method to evaluate the knowledge and focus on the most important issues. The questions were created in such a way as to test the learning outcomes, and in the specific case those were related to: geothermal cascading utilization, technicalities of geothermal resource utilization, circular economy, life cycle assessment, environmental impact assessment, financial modelling of geothermal projects, entrepreneurship, etc. After each online lecture, the student had to answer a set of dedicated questions and achieve a certain success. Otherwise, he had to repeat the quiz until he achieved a satisfactory result, and only then he could continue with the next lesson. As already mentioned, the questions focused on the most important topics of the lectures, which are considered to be mastered by every student in scope of Geo3EN curriculum. Students responded positively to this way of evaluating pedagogical tools. These questions were multiple choice and allowed for multiple attempts. This was meant to test the students' knowledge retention after the end of the recorded lecture.

Examples of quiz questions:

Geothermal fluid can be run sequentially through different energy extraction processes, each requiring a lower temperature than the previous. This is called:

Group of answer choices

a. Cascading

b. Direct use

c. Electricity generation

d. All of above.

Why are ‚critical minerals‘ important?

Group of answer choices

a. They are important for renewable energy technologies necessary to implement the energy transition and other advanced technologies

b. They are important for development of many advanced technologies

d. Western nations are certain that they have large resources of these minerals

e. There could be national vulnerability with respect to mineral processing *f. All of the above*

g. a. b. & e.

2.3 Group discussions and presentations after the field trips

The next advanced tool for testing/assessing knowledge and acquiring competences is group discussion/debriefing after the field trip. It was introduced by UniLaSalle University and regularly performed during the ISP in France. After each visit to the mine or other geological site, there was a discussion at the end of the day about what the students had seen and learned. The idea was for students to clearly and correctly formulate their observations, explain them scientifically, draw schemes and present them to other students. That is why during the entire ISP, students worked in groups and were given precise tasks and instructions on what to do. During the week of online lectures, all types of geological structures (mineral veins, fault zones, fractured rocks, etc.) that the students will encounter were theoretically explained, and during fieldwork students had to recognize them in mines, photograph, map, evaluate them in the context of geothermal potential. This kind of combination of theoretical and field work that complement each other is an excellent way to evaluate pedagogical tools; it is evident if the students acquired learning outcomes in the competence matrix, but more importantly if they are able to apply the knowledge from natural sciences to identify, formulate and analyze the given task.

2.4 Online questionnaire

The online questionnaire was performed in order to test the pedagogical tools and evaluate the intensive study programmes. The results of the questionnaire are discussed in detail in IO10 report. The main observations, additionally discussed during Teams meeting between students and teachers, are briefly given here:

- Students had the concerns about the amount and complexity of materials from certain scientific/engineering fields; the geology students about the lectures in mechanical/electrical engineering, and vice versa. From the beginning of the project, it was evident that students who do not have any prior knowledge of a certain field would find it difficult to follow the lectures. Especially when these areas of research are so different and do not have much in common. The standard teaching materials used by universities within their study programmes were therefore adapted so that all students could follow them equally successfully. The intention was not to simplify them too much, because then they would not fulfil the purpose of the study, but to present all important subjects/competencies in a way that everyone would understand them. The disadvantage of this approach is that there was not enough time, the online lectures were concentrated in one week, for the students to thoroughly study the materials. In addition, the lectures of different institutions (Uni Darmstadt, Uni LaSalle, Uni Zagreb) went successively from week to week, without a break. Furthermore, there was also the question of organization, i.e. the schedule, and whether it could have been organized better. Of course, the idea of the coordinator and the partners was to put as little burden on the students as possible, but since the implementation of such a project required the involvement of a large number of teachers, a compromise had to be found between the quality of teaching materials and the availability of teachers and students. Both students and teachers were aware of this problem, which is not easy to solve, but with their enthusiasm and commitment, they achieved the best possible results. Students appreciated efforts of the teaching staff and gave their best to attend and actively participate in classes. In the end, everyone made a maximum effort because it was in our interest that the program be completed successfully. The final comments of the students are nevertheless positive. There were some aspects that could be improved, but they were not essential, and the whole project was a successful experience.

- The final group project was quite demanding given the little time to complete it. The students worked on the project in parallel with other activities during the ISP. These were international groups of four students, one from each partner institution, and because of that, communication was somewhat difficult. An additional comment was that the project assignment was insufficiently explained and that the objectives were not presented clearly enough. The case study also involved the use of the DMS-TOUGE software, decision making support tool developed in scope of the Horizon MEET project [1]. The software enabled students, considering the type of energy that could be produced (heat or/and power), the geological context, the local energy supply and demand, the environmental impact, and societal aspect, to choose the optimal way for using the geothermal energy. Although it was a rather simple software to use, it required the input of a large amount of data about geothermal location that either were not available, or had to be prepared in a suitable way for which there was not enough time. All these comments were justified and in the future it will be necessary to make sure that the student groups and the task are defined earlier, that detailed project documentation is prepared beforehand and that some guidelines are given on how to structure the report. However, the students successfully completed the project, and more information is provided below.

2.5 Case study projects

The final capstone project demonstrates the students' ability to apply the acquired knowledge and critically apply it in a methodical way in solving a real scientific-engineering problem. The project was conducted in groups composed of four students (one from UniLaSalle, one from TU Darmstadt, one from Reykjavik University and one from University of Zagreb). There were six groups in total. The project assignment was to design geothermal plant at the location of Upper Rhine Graben taken into account geothermal potential, possibility of heat extraction, societal acceptance, economic profitability and environmental impact. The project tested all competencies students acquired during online lectures and ISP activities in all four partner institutions:

1. To extract the heat from geothermal reservoir a fracture networks needs to be established to allow the water to flow. The Schauinsland mine visited during the ISP in France served as an analogue to determine the connectivity between the faults. In this way it is possible to assume the interaction between faults to better estimate the movement of the fluid at depth. However, the nature of the faults themselves may or may not allow fluids to pass through them. Faults rich in clay allow very few fluids to pass. On the other hand, faults with large mineral veins allow a lot of fluid to pass. The study of the mine structures enabled students to distinguish between different kinds of faults (permeable/impermeable), find interactions between them, design a scheme of water interconnections underground and, finally, determine positions of injection well and pumping boreholes. The students devoted a good part of the report to describe and explain the mechanics of fluid flow, to which they attached cross-sections of the explored site, schemes of various

possibilities of fluid circulation within fractures and different models of interaction between faults, demonstrating the skills they acquired while visiting mines during the French ISP.

2. The potential of the geothermal reservoir depends, besides the possibility of water to circulate through the system of interconnected fractures, on a geothermal gradient which can be determined by studying geothermal rock properties that was done at TU Darmstadt. The second part of the project covered laboratory measurements carried out with samples taken from the geothermal site. Students documented their work in the laboratory to determine the petrophysical host rock properties: porosity, permeability, density, Young's modulus, Poisson's ratio, compressive strength, thermal conductivity, heat capacity, thermal diffusivity. They explained the equipment, measuring devices, methods and computation tools. These measurements were also important because the obtained data were used in the decision making support tool DMS-TOUGE. Students used this tool to evaluate the technical and economic feasibility and sustainability of the project. In addition, TU Darmstadt prepared a database with a comprehensive set of reservoir properties representative for the study area: transient measurements of temperature, mass flow rates, specific heat capacity, and viscosity at the production wells. These data were used by students to calculate geothermal power plant parameters, power output, energy generation and efficiency.
3. Students could choose between three types of power plants: dry steam, flash steam and binary cycle plants with organic Rankine cycle. They decided to use the last type because of low temperature/low enthalpy geothermal reservoir. After that, they needed to calculate the heat input based on the brine mass flow, specific heat and the temperature difference at the inlet and outlet boreholes. Another important parameter is efficiency which depends on the brine temperature and is very low. Students had to find this information in the literature. The final result of this simple calculation was the electric power of the power plant. In addition, operational parameters of plant's main equipment (turbine, heat exchanger, condenser) were also selected. The mass flow of the organic fluid was calculated taking into account the enthalpy difference, which is important because the size of the power plant depends on it. As mentioned earlier, the goal was not to use complicated calculations or numerical tools, but to demonstrate an understanding of power plant operation and physical laws through simple calculations. The power plant is connected to the electric grid via a transformer, and the students had to choose the optimal size of the transformer according to the parameters of the nearest substation and the output voltage of the generator. This means that they should have researched connection options and potential electricity buyers. The technical analysis was followed by the economic analysis.
4. Students used decision making support tool the integrate economic and financial parameters that support the decision-making process. These parameters consider the technology, investment, operation and maintenance costs for the different phases of the project (permitting, exploration and drilling). The environmental impacts of the project are assessed in terms of a set of parameters including land use intensity, noise, and seismic hazard. The DMS-TOUGE calculates the avoided CO_2 emissions based on country-specific datasets of emission factors. The results are then interpreted and discussed to evaluate the sustainability of the operations. The quantitative assessment of environmental impacts provided by life cycle assessment is utilized to evaluate the sustainability of the project. The life cycle assessment is a complex quantitative tool for environment management programme that takes into account the whole geothermal cycle, from site exploitation and drilling to power plant operation and waste management. Beside using the software, students needed to find many missing parameters and information from the literature. Some of the aspects, like the societal acceptance are hard to quantify making the last part of the project very demanding. However, students managed to identify all the aspects of geothermal

power utilization, being positive or negative. It was an interdisciplinary research with many unknowns but all project groups presented well-founded results with unequivocal conclusions.

3 Summary

The innovative pedagogical tools were tested continuously during the Geo3EN project: during lectures, field work, or during visits to power plants and other technical facilities. Testing, monitoring and review are an integral part of a multidisciplinary international project that involves close cooperation between teachers and students. Reactions of students and teachers served to improve the teaching process and materials, and the realization of the field work. Five types of evaluation methods were used:

1. Group discussions and exercises after the lectures
2. Quizzes after the lectures
3. Group discussions and presentations after the field trips
4. Online questionnaire
5. Case study projects

Each of these methods had a different purpose, and served not only to test students' knowledge, but also to improve teaching methods and enable students to understand the material more easily. It was important that all students, regardless of their background master basic knowledge in geology, drilling, engineering and entrepreneurship, and the testing of pedagogical tools helped greatly with that. Student work on the final capstone project was the most important evaluation method. It demonstrated the students' ability to apply the acquired knowledge in a methodical way and tested all competencies students obtained during the project. The final comments of the students, but also of the teachers, were positive. There were some aspects that could be improved, and in the future they will need to be taken into account, but they were not essential, and the whole project was a successful experience.

4 References

[1] Sara Raos, Ivan Rajšl, Tena Bilić, MEET project, H2020 Grant Agreement N° 792037, Deliverable D.7.1 Open access decision support tool for optimal usage of geothermal energy, WP7: Economic and environmental assessment for EGS integration into energy systems