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Implementation of innovative teaching methods in geotechnical engineering education via a collaborative teaching network

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ABSTRACT: The continuous improvement of teaching methods in geotechnical engineering is essential to equip students with sound knowledge and practical skills. This paper highlights collaborative efforts within the Geotechnical Network for Innovation in teaching and Learning (German: Geotechnik-Netzwerk für Innovationen in der Lehre, *GeNIaL*), an informal teaching network of geotechnical professors from Germany, Austria and Switzerland, and their role in developing and implementing innovative teaching approaches. The *GeNIaL* network, founded by the authors, fosters collaboration through the exchange of ideas and resources. Members of the network have been successfully developing digital teaching materials, e.g. (interactive) videos and screencasts, 3D lab tours, electronic tests and flipped classroom concepts. These efforts and various network meetings have created a robust foundation for larger teaching projects within the community. As specific examples for the recent efforts, two projects are presented in more detail: educational escape rooms and concept inventories. Educational escape rooms were developed to complement traditional soil mechanics laboratory courses. These interactive game scenarios, covering topics like soil classification, sieve analysis and Proctor tests, engage students in collaborative problem-solving while enhancing theoretical and practical understanding. Another current activity is the development of concept inventories for geotechnical engineering. These are instruments designed to evaluate students' understanding of fundamental concepts, such as (effective) stresses, soil strength and stiffness. Validated through a first test phase at six universities, these inventories are presented, e.g. for use as pre- and post-tests or in a peer instruction setting. Together, these collaborative initiatives within the *GeNIaL* network underscore how a network-driven approach can innovate and advance geotechnical engineering education.

KEYWORDS: Collaborative teaching, teaching network, educational escape rooms, concept inventories, engineering education.

1 INTRODUCTION

Engineering education, in general, faces increasing demands for modern, engaging, and effective teaching approaches. Traditional lecture-based formats are complemented by interactive, student-centered learning environments, making use of digital teaching resources. However, depending on the type and intended quality, the creation of these teaching materials can be very time-consuming and mean a lot of extra work for educators.

Against this background, and stimulated by individual work during the Covid pandemic, the Geotechnical Network for Innovation in teaching and Learning (German: Geotechnik-Netzwerk für Innovationen in der Lehre, *GeNIaL*) was established in 2022 to foster collaborative development and implementation of innovative teaching methods in geotechnical education across Germany, Austria and Switzerland.

This paper presents the *GeNIaL* network and illustrates its achievements over the last couple of years. Two projects are presented in detail: the development of educational escape rooms and first steps to define concept inventories tailored to geotechnical engineering. These efforts exemplify how shared expertise and collaborative initiative can enrich engineering education and stimulate similar activities within the ISSMGE community.

2 FORMATION AND FRAMEWORK OF THE GENIAL NETWORK

2.1 *Formation and structure*

The *GeNIaL* network was initiated in 2022 by Professors Ansgar Kirsch (FH Aachen), Katharina Kluge (HS Mainz), and Christoph Budach (TH Köln), who share a strong commitment to innovation in geotechnical engineering education. Recognizing the limitations of isolated efforts, they further elaborated the idea to gather like-minded lecturers within the German-speaking community into an informal network for regular exchange and joint development of teaching materials.

This initiative gained momentum through a comprehensive survey among German-speaking geotechnical departments (Kluge et al. 2022). After the Covid pandemic, one aim of this survey was to capture the use of digital teaching materials and corresponding tools in the field of geotechnical engineering.

Moreover, challenges and opportunities for production and application of such tools were asked of the participants. A total number of 39 replies from 31 (technical) universities and 60 universities of applied sciences from Germany, Austria and Switzerland were systematically evaluated.

Among others, the results showed that quite a few tools and online material had been produced, mostly for providing information (e.g. PDFs or recorded lectures), visualizing content (e.g. videos or animations), communicating / collaborating (e.g. online lectures, discussion forums, chats or blogs) and testing (e.g. electronic exercises and quizzes). Tools for reflection (e.g. e-portfolios or digital journals) or game-based learning were hardly conceived.

The greatest barriers to creating digital teaching materials are reported to be the high time investment required and the limited availability of (qualified) personnel (Figure 1). In contrast, technical equipment and personal motivation are largely not considered major obstacles.

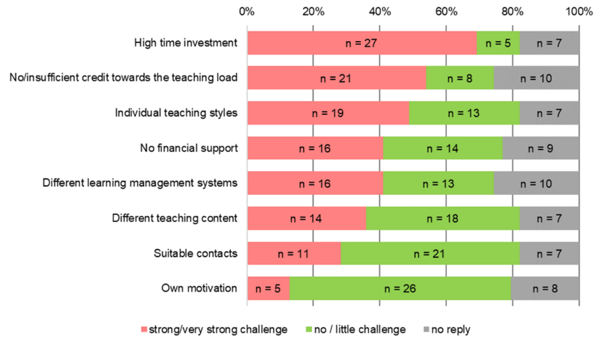

Figure 1. Opportunities and threats for collaboration (according to Kluge et al. 2022, translated to English).

Similar barriers were mentioned with respect to collaboration across teaching institutions. In fact, the survey revealed that only four of the participants had made efforts to jointly produce teaching materials, including the three authors themselves! This was a surprise as the core topics in soil mechanics and foundation engineering are identical at most universities. As a last part of the survey, participants were invited to join an informal network to regularly exchange ideas, experiences and to share and create teaching material together.

Figure 2. Network members during a conference in 2024.

2.2 *Activities and dissemination of results*

Since 2022, approx. 20 meetings of the *GeNIaL* network have taken place up to now, mostly as online meetings with an average of 12-15 participants from Germany, Austria and Switzerland. But also several face-to-face meetings were organized in Mainz and Aachen, or took place during conferences (Figure 2).

All meetings are dedicated to specific topics for teaching geotechnical engineering. The following non-exhaustive list highlights the variety of topics that has been addressed so far. Where applicable, a literature reference or a URL illustrate where to find further information:

- One of the authors' first projects in 2021 was the production of educational videos for laboratory and field tests. Supported by teaching experts at the respective universities, scripts for such videos were collaboratively developed, film material produced, videos cut and voiceover added. Finally, the whole team was responsible for quality assurance. So far, 20 video clips have been published under a creative common license and can be watched (with English subtitles) on: https://www.youtube.com/@Geotechniksichtbarmachen Supplementary exercises and test questions, which are available on request, help to integrate these videos into lectures or flipped classroom settings.
- Within the framework of Scholarship of Teaching and Learning (SoTL) the authors worked out in 2022 a methodology to tackle bottlenecks in students' understanding of the concept of vertical stress distribution in soil. Termed "Decoding the disciplines" they took part in structured interviews with didactics experts, described their expert way of thinking in detail and identified together, why students might struggle with this concept. As a result, a physical model of a layered soil profile was developed, together with corresponding test questions for use in class. For further details, see Barnat et al. (2022).
- To facilitate understanding of a geotechnical laboratory setup and corresponding tests, virtual 3D-tours have been created with 180° pictures and interactive online teaching material: https://www.geonetic.de/boden-mechanik/360deg-laborrundgang/
- Also, an interactive laboratory simulation has been produced by one of the network members and published as OER. This simulation puts students into the role of a geotechnical engineer who needs to derive parameters from standard laboratory tests. This simulation is available as OER from: https://www.twillo.de/edu-sharing/components/render/cad8de36-d506-4955-bc38-dce5337c2e86
- Online tests ranging from single and multiple choice questions up to more complex test questions with randomized input parameters (e.g. r/exams or STACK questions) have been developed and exchanged. These can be embedded into standard learning management systems and allow students to test their knowledge at any time.
- Teaching material, demonstration experiments and exam questions have also been generously shared or even developed together. A combination of online and offline teaching material within a flipped classroom setting has been implemented at several universities across the GeNIaL network.
- Ideas and solutions on how to integrate topics such as sustainability and digitalization (e.g. BIM applications) into geotechnical courses have been discussed intensively. Internal and external experts from universities or specialized companies have provided fruitful insight.

In addition, two more recent projects of the *GeNIaL* network comprise the development and application of a geotechnical escape room as well as first steps towards development of concept inventories to assess the effectiveness of teaching geotechnical core concepts. These will be presented in more detail in the following section of the paper.

The network keeps evolving as new members join the group while others quit, mostly due to retirement. All activities are presented together with a short overview over current members on the network's website: www.genial-geotechnik.de

3 SELECTED TEACHING INNOVATIONS DEVELOPED BY THE NETWORK

3.1 *Educational Escape Rooms in Soil Mechanics*

3.1.1 *Introduction*

Escape rooms are widely known in entertainment but have recently emerged as pedagogical tools in engineering education. Such educational escape rooms - also called eduscapes - are game-based learning environments designed to enhance student engagement and deepen understanding through collaborative problem solving. In the field of geotechnical engineering, they can be used to enliven laboratory courses while reinforcing theoretical knowledge as well as technical and social skills. Students are challenged in an unusual way to solve discipline-related tasks and other puzzles within a limited time frame.

The authors adapted this format to create engaging laboratory experiences at universities of applied sciences in Mainz, Cologne and Aachen. The learning objectives targeted with these eduscapes cover technical aspects, e.g. carrying out and evaluating standard laboratory tests in soil mechanics or classifying soil according to national standards. But, also social skills are addressed, e.g. working and communicating well in a team under time pressure.

In the following, selected examples are given for the sequence of puzzles and the tasks themselves. Moreover, it is illustrated how these eduscapes have been implemented at the participating universities. More detailed information can be found in Kluge et al. (2025).

3.1.2 *Structure and puzzles*

The individual puzzles are usually tailored to a background story or a meta-puzzle that leads to a final solution or the "escape" out of the laboratory. These puzzles can be aligned as an open path, in which puzzles can be solved independently, or as a linear path, in which puzzles must be solved in a sequential order. Multilinear paths are also possible, in which several linear puzzles can be worked on in parallel, thus allowing more flexibility (Figure 3). A time frame between 60 and 90 minutes and groups of 3 to 5 students have been found suitable.

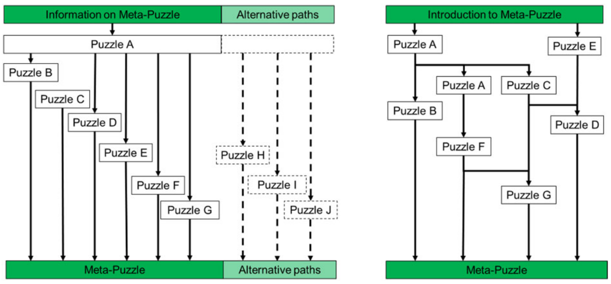

Figure 3. Examples for the structure of an eduscape (left: open path, right: multilinear path).

The implemented puzzles cover actual laboratory work such as the determination of a passing fraction for a 2 mm sieve (Figure 4), the derivation of the water content of a fine-grained soil making use of a microwave or the determination of the soil's in situ density from a core cutter sample.

But, carrying out the whole test procedures of various tests can be time-consuming. Therefore, many puzzles are based on given measurements, which then have to be evaluated to find the solution code.

These specific geotechnical challenges are flanked by logic puzzles from the literature or internet sources, as well as the fact that some objects required for the solution of the task are hidden in the laboratory.

Mesh size [mm]	Retained mass [g]	Retained fraction [%]	Passing fraction [%]
63	0,0	?	?
20	40,0	?	?
6,3	460,0	?	?
2,0	660,0	?	?
0,63	546,0	?	?
0,2	?	?	**?**
0,063	20,0	?	?

Figure 4. Example for the puzzle "sieve analysis" in which the passing fraction of the 0,2 mm sieve leads to a digit for the solution code.

3.1.3 *Implementation into geotechnical laboratory classes*

Targeted at 3rd semester civil engineering students, Eduscape Mainz is integrated as the final session of the soil mechanics laboratory course. Students, already familiar with laboratory tests through lectures, instructional videos and their laboratory course, revisit key experiments. The eduscape challenges them to deduce which tests yield necessary values for unlocking a final code. Tasks cover six core tests (e.g. sieve analysis, Atterberg limits, Proctor test). A short debriefing after the eduscape session provides valuable feedback for the students and ensures that the educational objectives are met. Though tested only once so far, feedback has been collected and used to refine the setup for broader implementation.

At TH Köln, where large cohorts up to 200 students per semester prevent early hands-on laboratory experience, Eduscape Köln serves as an engaging recap tool for 3rd semester students. Designed as part of a funded teaching innovation project, the game challenges the students to follow one of six possible paths (cf. Figure 3, left). The start is based on an initial test result (e.g. water permeability), which can be adapted to the respective group. This makes it possible to offer a fresh experience in following sessions. Students analyze various test results (e.g. dynamic probing light (DPL) compaction or Atterberg limits) and carry out some partial procedures themselves. The eduscape is accompanied and monitored by members of the laboratory staff, which provide occasional hints during and feedback after the session.

Eduscape Aachen was developed as a response to an observed decline in student motivation. It offers a voluntary, game-based alternative to standard laboratory classes, blending subject-specific tasks (e.g. grain size distribution, interpretation of a hydrological map) with logic puzzles. It emphasizes problem-solving and teamwork over test execution and is supposed to be fun, thus leaving a lasting impression on the students. The design includes physical objects like boxes and locks, while avoiding digital distractions to keep students focused on tangible experiences. Though not formally embedded in the curriculum due to lack of resources, the concept has undergone several student-tested iterations and adaptations since 2021 to improve usability.

3.2 *Development of concept inventories for geotechnical education*

3.2.1 *Introduction*

The discussion on core geotechnical skills for civil engineers within the *GeNIaL* network stimulated the idea to develop concept inventories for geotechnical engineering (Kirsch et al., 2025). Concept inventories are instruments to assess students' understanding of a specific set of fundamental concepts for a given subject (cf. Hestenes et al., 1992). An inventory is usually a set of multiple-choice questions, each question with one (or more) correct answer(s) and several distractors, which cover typical misconceptions for a specific topic.

The primary goal of a concept inventory is not to obtain a summative assessment of student learning, but its purpose is rather to provide formative assessment of teaching. Thus, it is possible to uncover and address bottlenecks in the students' conceptional understanding already during the teaching process. The work done by Kirsch, Fellin and Sonnenberg with support by the *GeNIaL* network covers some steps of the general process to develop such inventories as described by Adams & Wieman (2010).

3.2.2 *Exemplary questions and first implementation*

Influenced by the network members' own experiences, educational literature (e.g. Atkinson, 2008), industry expectations, and professional accreditation bodies the *GeNIaL* network adopted an iterative approach to distill six geotechnical core competencies required by civil engineering graduates at bachelor-level. These include soil classification, (effective) stress calculations, understanding soil stiffness and settlement, applying shear strength models and evaluating earth pressure. To assess the learning process for these goals, a targeted set of ten multiple-choice questions was produced by Kirsch et al. (2025). Two examples for such questions are presented in Figure 5.

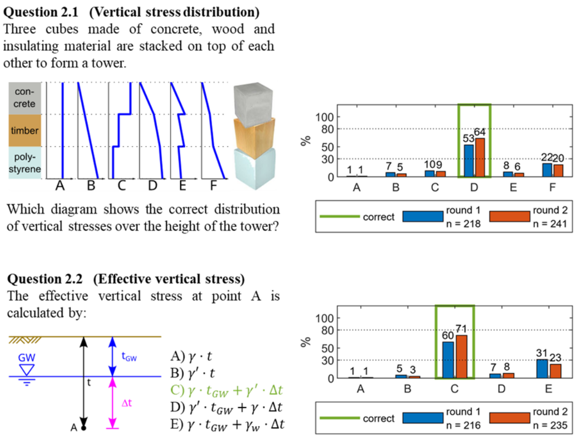

Figure 5. Questions on stress distribution in soil together with cumulated results from a recent peer instruction implementation at six universities.

To gain experience, these questions were tested during the winter term 2024/25 in a peer instruction setting (cf. Crouch & Mazur, 2001) at six universities (of applied sciences) in Germany and Austria. This involves students answering conceptual questions individually ("round 1" in Figure 5), discussing their reasoning with peers, and then re-evaluating their answers ("round 2" in Figure 5). Finally, both voting results and the correct solution(s) are presented and further evaluated and discussed in class. This engaging method is an active learning strategy that encourages students to generate knowledge collaboratively.

The survey revealed varying levels of student understanding. While certain concepts are well understood, misconceptions persist in areas such as soil stiffness and foundation width effects. The peer teaching method proved effective in testing conceptual understanding. However, some questions were found to be either too easy or too difficult, requiring further refinement.

3.2.3 *Further steps towards concept inventories*

Following the structured approach provided, future work will focus on refining the test questions, developing concept inventories, and presenting them to a wider geotechnical (academic) community. Kirsch et al. (2025) believe that these inventories offer long-term benefits for both teaching practice and academic planning. They prompt educators to identify and reflect on the key concepts and skills that should underpin geotechnical engineering education, leading to clearer learning objectives and more targeted teaching strategies. Additionally, the nature of concept inventory questions makes them effective tools for evaluating student understanding before and after a course.

Beyond individual courses, concept inventories can also promote alignment and collaboration among educators, institutional bodies, and professional associations, helping to strengthen and coordinate teaching efforts across the field.

4 BROADER IMPACTS AND FUTURE DIRECTIONS

Beyond the above mentioned flagship projects, the *GeNIaL* network has supported the development of diverse digital teaching tools, including interactive videos, screencasts, electronic exams, and flipped classroom modules. The network's distributed structure and shared goals have created a robust and sustainable framework for continued collaboration and innovation.

Looking forward, *GeNIaL* aims to expand its reach by inviting more colleagues, offering open-access teaching resources, and exploring new topics such as virtual reality applications and cross-institutional teaching collaborations. The experience of *GeNIaL* serves as a model for how informal academic networks can achieve meaningful and scalable impact.

5 CONCLUSIONS

The *GeNIaL* network demonstrates the power of collaboration for innovation in geotechnical engineering education. By leveraging collective expertise and shared resources, the network has created practical, engaging tools that respond to today's educational needs. E.g. educational escape rooms offer tangible benefits to student learning and concept inventories help to address bottlenecks in students' understanding and shape a course design.

Through its ongoing activities and open, inclusive approach, *GeNIaL* continues to shape the future of geo-education. The network encourages similar initiatives in other engineering fields and invites the educational community to collaborate.

6 ACKNOWLEDGEMENTS

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