Portable Hands-On Experiments in Geotechnical Education

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Abstract

This article focuses on portable, hands-on experiments in geotechnical engineering that serve as an entry point into the tutorials in Soil Mechanics and Foundation Engineering at the University of Innsbruck. Ten small portable geotechnical experiments were developed to demonstrate geo-mechanical relations during class in a clear and comprehensible way. To determine the degree of student acceptance and possible learning benefits, the experiments were evaluated with a questionnaire. This evaluation showed that experiments in geo-mechanical engineering were well received and are appropriate visualization tools. The experiments were highly appreciated by the students, who reported that they helped to make the course material more comprehensible and clear.

1. Introduction

The tutorial in Soil Mechanics and Foundation Engineering at the University of Innsbruck takes place in the second year of the bachelor program in civil engineering. It consists of 45 hours of face-to-face classroom events (4 ECTS-CP) in addition to lectures (60 hours of presentations, 6 ECTS-CP) in which the fundamentals of geotechnical modeling are presented. The course enrolls up to 140 students, who are subdivided into four groups. We apply the method of flip teaching, which means in this case that the students must calculate basic geotechnical problem sets at home. The results of their calculations are discussed in the subsequent course meetings.

The structure of the course meetings (90 minutes long in total) is as follows:

We start with a short warm up where we use the small portable geotechnical experiments. Alternatively, we administer quizzes in the format of "Who Wants to Be a Millionaire?" or we present case studies of legal suits seeking damages where students act as geotechnical experts in court. The main part of each class meeting (45 minutes) is devoted to the discussion of the homework. Students compare their results and their calculation methods in small groups of up to four members. Additionally, they must solve or answer up to six supplementary simple calculations or questions. The course meetings end with a recapitulation of results (35 minutes), where randomly selected students present their examples on the blackboard and answer the supplementary questions.

Table 1: Facts on the hands-on experiments

◦ **10 portable hands-on experiments** on geomechanical relations
◦ **Demonstration** of an experiment in each lesson for the **first 10 minutes**
◦ **Bachelor** course, 2nd year: *Soil Mechanics and Foundation Engineering*
◦ Up to **140 students** in 4 groups
◦ **Evaluation** with a questionnaire with 6 statements, 7 closed questions and 3 open questions

This article focuses on the portable hands-on experiments that serve as an entry point into the majority of the lessons. The main facts are summarized in Tab. 1. To determine the acceptance and benefits from the perspective of the students we evaluated the experiments with a questionnaire.

2. Experiments

The ten different portable hands-on experiments (Tab. 2) used in the course

Table 2: List of portable hands-on experiments

No.	Experiment	Fig.
1	Soil classification: Fine grained soil	1
2	Soil classification: Coarse grained soil	2
3	Dilatancy	3
4	Sand anchor	6
5	Slope stability	8
6	Earth pressure	10
7	Stress in subsoil	12
8	Glove	11
9	Liquefaction, earthquake	13
10	Stability of towers	14

Soil Mechanics and Foundation Engineering are explained briefly below.

2.1 Soil Classification: Fine-grained Soil

Four boxes with fine-grained soil are presented to the students (Fig. 1). They contain two types of soil (clay and silt) each dry and wet. Hence, the students initially get the impression of seeing four different soils. The grain size distribution lines and the plasticity diagrams from the laboratory for both soils are given to the students. Their task is then to assign these data to the appropriate samples. Thanks to this experiment the strong influence of water on the consistency of fine-grained soil can be easily visualized

2.2 Soil Classification: Coarse-grained Soil

Three boxes with coarse-grained soils are presented (Fig. 2). Three grain size distribution lines from the laboratory for each sample are given to the student in a printed version. The task for the students is to match the three grain size distribution lines with the correct samples.

Figure 3: Dilatancy

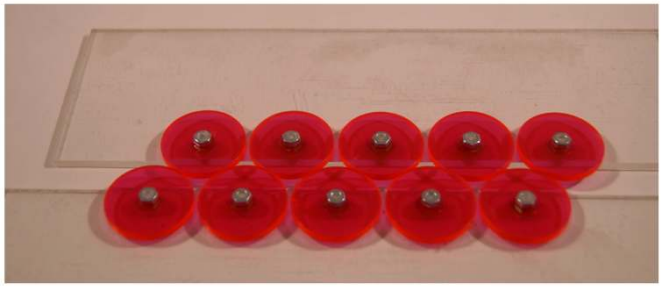


Figure 4: Dense sand

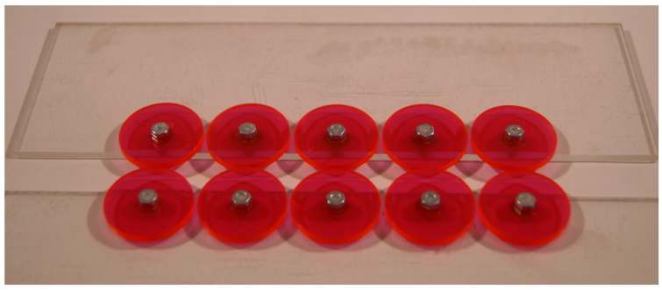


Figure 5: Loose sand

2.3 Dilatancy

This experiment (Fig. 3) is well known, e.g. [1, 2]. Students must estimate the movement of the water table in the pipe when the rubber ball is squeezed. For a rubber bulb filled with water, only the water table will obviously rise. On the other hand, for a second rubber bulb filled with dense sand and water the water table will fall. We can explain this dilative behavior due to shearing with the help of a grain model (Fig. 4 and 5).

Figure 6: Sandanchor

Figure 7: Sandanchor

2.4 Sand Anchor

This experiment highlights the effect of dilatancy on shear strengths in confined situations. A reinforcing steel bar can be plugged into a hole of a concrete cylinder (Fig. 6). The gap between the bar and the concrete is filled with sand and compacted by lightly tapping on the cylinder (Fig. 7). The concrete cylinder can then be lifted by raising the bar due to the dilatancy of the dense sand, which increases the horizontal stresses and therefore the frictional shear stress.

2.5 Slope stability

This experiment consists of a sand chute filled with angular coarse-grained sand (Fig. 8). The inclination of the chute can be increased until a sand avalanche is initiated. The students must estimate the maximum inclination angle before the experiment is performed. A connection with the theory of infinite slope stability can be given where the peak friction angle of cohesionless soil is equal to the maximum inclination of the slope (in this case 36 degrees , see Fig. 9). The angle of repose is approximately the critical state friction angle of a soil (in this case 30 degrees , see

Fig. 9), which turns out to be lower than the peak friction angle.

Figure 8: Sand chute

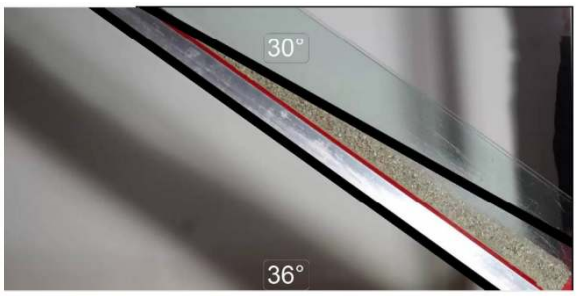


Figure 9: Maximum inclination of the slope

2.6 Earth Pressure

We visualize the earth pressure theory with the help of a sandbox (Fig. 10), whose left wall can either be moved away from the soil or against the soil. The students must estimate the anticipated deformation in the soil before the experiment is performed. During the experiment, one can see a sliding earth wedge, which can be directly related to Coulomb's law, which describes the electrostatic interaction between electrically charged particles. This experiment is much simpler than using colored sand layers as proposed in [1] and a bit more realistic than using wooden sticks as proposed in [3].

Figure 10: Earthpressure

Figure 11: Glove

2.7 Stress in subsoil

This experiment helps to illustrate the origin of the vertical stress in soil. The two pipes in Fig. 12 contain the same mass of sand, which is revealed to the students together with the geometry of the problem. Students must calculate the vertical stress at the bottom assuming the wall friction is zero.

Figure 12: Stress in subsoil

Figure 13: Liquefaction, earthquake

Figure 14: Stability of towers

2.8 Glove

This well-known experiment [2] of a sand filled glove helps to explain the fundamental principle of effective stresses (Fig. 11). On can perform a handshake with the initially soft glove and repeat the handshake after creating a vacuum inside the glove.

2.9 Liquefaction from Earthquakes

This experiment[1] can be used to explain soil liquefaction due to earthquakes. A bottle (Fig. 13) is filled with sand and water. The bottles also contain perspex balls with a steel inlay, such that their density is higher than the slurry density when the bottle is shaken and lower than density of the deposited sand. The experiment starts with shaking the bottles and waiting for the sedimentation to end. The perspex balls are then buried. Tapping with a hammer at the side of the bottle will induce shear waves, which liquefies the soil and the perspex balls will now blob up due to their inherent buoyancy.

2.10 Stability of towers

Students must try to build the tallest possible towers with blocks of wood (Fig. 14) on two foam pads: a stiff one and a soft one. The tower on the stiff foam pad will be taller, an outcome that can be nicely related to the theory of an inverted pendulum, which explains the differing stability of the two towers.

3. Evaluation (statements and closed questions)

Our questionnaire included six statements (with rankings), seven closed questions and three open questions (see Appendix). Sixty-eight questionnaires have been distributed during a classroom meeting and 64 collected (return rate 94%). The answers to the closed questions are summarized in Tables 3 and 4. The evaluation yielded a positive feedback, e.g. 96% of the students agreed in whole or in part with the statement that the experiments provided a good start for each lesson (see Fig. 15) and 66% agreed in whole or in part that they learned a lot from the experiments (see Fig. 16). Only 3% said that the experiments were superfluous (see Fig. 17). A detailed analysis of the student responses is given in Table 3.

In Table 4 the approval rates for different statements for each experiments are shown. A 100% approval rate corresponds to the students answer "It's true." 50% approval rate corresponds to the students" statement: "I am neutral," and 0% means "Not applicable." An empty box was related to "No recollection." The mean values of the approval rates for each experiment and each statement as well as the mean values of the approval rate and the standard deviation for each statement for all experiments are shown. The rates of "No recollection" are given in parentheses.

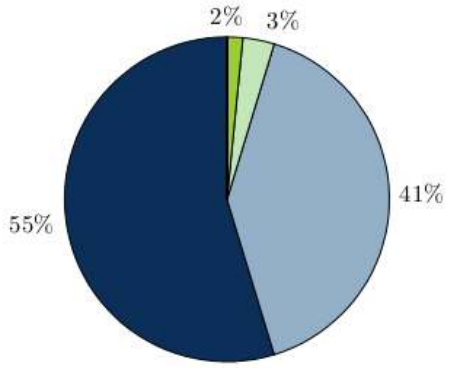


Figure 15: Answers to the question: How much do you agree with the following statement? *The experiments were a good start for each lesson.*, legend see Fig. 18

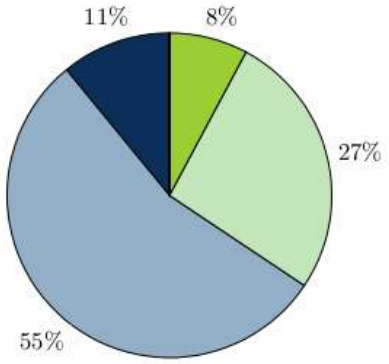


Figure 16: Answers to the question: How much do you agree with the following statement? *I learned a lot from the experiments.*, legend see Fig. 18

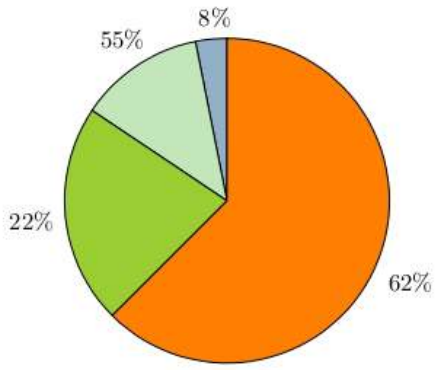


Figure 17: Answers to the question: How much do you agree with the following statement? *The experiments were superfluous.*, legend see Fig. 18

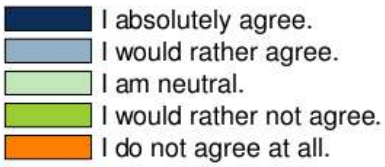


Figure 18: Legend to the Fig. 15, 16 and 17

Table 3: Rate of agreement to each question

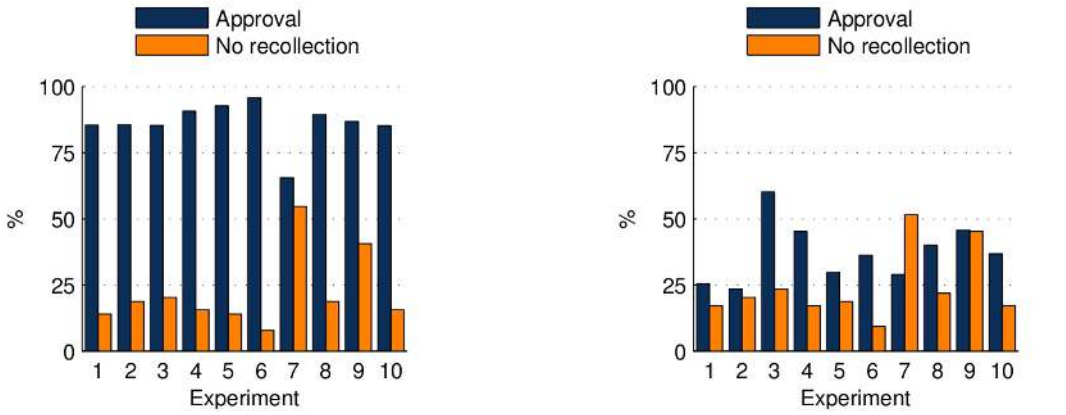
Questions: How much do you agree with the following statements?	I absolutely agree.	I would rather agree.	I am neutral.	I would rather not agree.	I do not agree at all.	number of valid answers.
The experiments were a **good start** for each lesson.	**55**	41	3	2	0	64
The experiments were a **waste of time**.	0	0	8	41	**52**	64
I **learned a lot** from the experiments.	11	**55**	27	8	0	64
The experiments were **boring**.	0	0	11	**53**	36	64
The experiments were a good **complement to the calculations**.	**37**	34	19	8	2	64
The experiments were **superfluous**.	0	3	13	22	**62**	64
The experiments should definitely be **continued**.	**71**	19	10	0	0	63

Generally speaking, the experiments show similar patterns of acceptance. Only Experiment 7 scores lower compared to the other experiments. Note also that the rate of "No recollection" is higher for Experiment 7 than for the other experiments. An average approval rate of 86.3% showed that students believe the experiments foster understanding for geotechnical modeling (see Fig. 19(a) and Tab. 4). A mean approval rate higher than 40% for Experiments 3, 4, 8 and 9 indicates that they showed unexpected results (see Fig. 19(b) and Tab. 4). A mean approval rate higher than 50% for experiments 3, 4, 6, 8, 9 and 10 suggests that students found them amusing (see Fig. 20(a) and Tab. 4).

Those experiments with unexpected outcomes are more likely to be considered amusing than others. The most boring experiments were fine-grained soil (33.7% approval rate for experiment 1) and coarse-grained soil (35.0% approval rate for experiment 2). An average approval rate of 92.7% indicated a

desire to continue the experiments in geotechnical education, see Fig. 20(b).

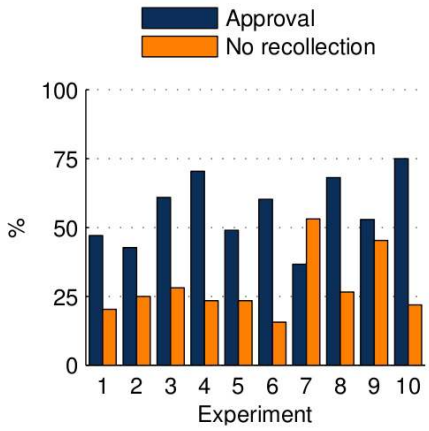
In order to estimate which experiments were more popular than others, we worked out an overall ranking (see Table 5 below). The rank order of the experiments follows from the mean approval rate 1nai of each experiment for all statements (n = 6). The positive statements are considered with ai = approval (%). The negative statements are considered with ai = 100% – approval (%). The experiments involving the sand anchor and earth pressure are ranked just ahead of glove, stability of towers, and dilatancy. The only experiments below 75% are fine-grained soil, coarse-grained soil, and stress in subsoil. The experiment stress in subsoil was the experiment with the highest rate of "No recollection." (That is, students could not remember this experiment).



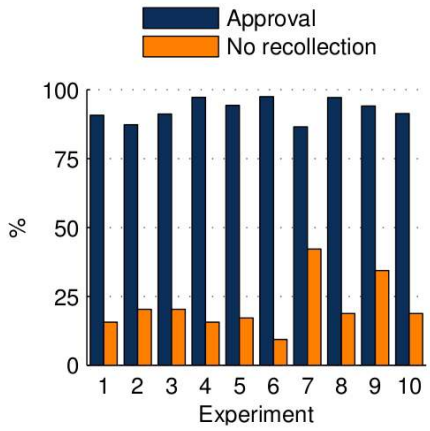
(a) *The experiment fosters understanding for geotechnical modelling (theory).*

(b) *The experiment showed an unexpected outcome/result.*

Figure 19: Approval rate and rates of "No recollection" to the statements in (a) and (b) for every experiment, see Tab. 2 for experiment numbers.



(a) *The experiment was funny.*



(b) *The experiment should be continued.*

Figure 20: Approval rate and rates of "No recollection" to the statements in (a) and (b) for every experiment, see Tab. 2 for experiment numbers.

Table 4: Approval rate to each statement: 100%: *"It applies."*, 50%: *"I am neutral."*, 0%: *"It does not apply."*; Mean approval rate and standard deviation for each statement and each experiment and average approval rate for each statement for all experiments. Rate of *"No recollection"* in parenthesis. Total number of evaluation sheets: 64

Statements	**Experiment** (see Tab. 2 for experiment numbers)									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
The experiment **fosters understanding** for geotechnical modelling (theory).	85.5 (14.1)	85.6 (18.8)	85.3 (20.3)	90.7 (15.6)	92.7 (14.1)	**95.8** (7.81)	65.5 (54.7)	89.4 (18.8)	86.8 (40.6)	85.2 (15.6)
	Average approval rate: 86.3 / Standard deviation: 8.1									
The experiment showed an **unexpected** outcome/result.	25.5 (17.2)	23.5 (20.3)	**60.2** (23.4)	45.3 (17.2)	29.8 (18.8)	36.2 (9.38)	29.0 (51.6)	40.0 (21.9)	45.7 (45.3)	36.8 (17.2)
	Average approval rate: 37.2 / Standard deviation: 11.2									
The experiment was **funny**.	47.1 (20.3)	42.7 (25.0)	60.9 (28.1)	**70.4** (23.4)	49.0 (23.4)	60.2 (15.6)	36.7 (53.1)	68.1 (26.6)	52.9 (45.3)	75.0 (21.9)
	Average approval rate: 56.3 / Standard deviation: 12.7									
The experiment was **boring**.	33.7 (18.8)	**35.0** (21.9)	20.2 (26.6)	16 (26.6)	17.7 (25.0)	14.2 (17.2)	27.4 (51.6)	21.7 (28.1)	15.7 (45.3)	14.6 (25.0)
	Average approval rate: 21.6 / Standard deviation: 7.8									
The experiment should be **continued**.	90.7 (15.6)	87.3 (20.3)	91.2 (20.3)	97.2 (15.6)	94.3 (17.2)	**97.4** (9.38)	86.5 (42.2)	97.1 (18.8)	94.0 (34.4)	91.3 (18.8)
	Average approval rate: 92.7 / Standard deviation: 4.0									
The experiment should be **removed** from the program.	14.4 (18.8)	**16.0** (21.9)	15.6 (25.0)	10.2 (23.4)	6.1 (23.4)	7.4 (15.6)	11.1 (43.7)	7.8 (25.0)	11.3 (37.5)	9.4 (25.0)
	Average approval rate: 11.0 / Standard deviation: 3.4									

4. Student Feedback (Open Questions)

Thirty-nine students took the opportunity to give us personal feedback in response to three open questions, as follows:

- I liked ...
- I did not like ...
- Further comments.

There were 36 comments on what students liked, 15 comments on what they did not like and 3 “further comments.” The positive comments included facts that the experiments show practical relevance, they enhance motivation and understanding, they deepen theoretical knowledge, they act as a relaxed entry into the course, they facilitate the possibility to participate actively. Students further liked the simple demonstration of complex issues in the experiments and the fact that their practical relevance fosters understanding of soil mechanical behavior. The main criticism was that the time to do the experiments was too short or that there was less time for calculations because of the experiments. One student wrote that he/she did not like the experiment coarse-grained soil. However he/she admits that it was important for their understanding. Further comments included the need for more time for the experiments, a wish for more laboratory experiments, or the observation that there were not enough experiments.

Table 5: The ranking of the experiments follows from the mean approval rate $\frac{1}{n}\sum_{1}^{n} a_i$ of each experiment for all statements ($n = 6$). The positive statements are considered with a_i = approval (%). The negative statements are considered with $a_i = 100\%$ − approval (%) in this ranking.

Mean approval (%)	Experiment
80	4: Sand anchor
78	6: Earth pressure
77	7: Glove
77	10: Stability of towers
77	3: Dilatancy
75	9: Liquefaction
74	5: Slope stability
67	1: Fine grained soil
65	2: Coarse grained soil
63	7: Stress in subsoil

5. Teachers' Impressions

The teachers had the impression that students did not want to leave their seats to come to the front of the class for the demonstration of the experiments. They also had the impression that the students did not like to give their opinion in class and thereby run the risk that it might be wrong. However, the students did like to perform the experiments themselves, not just in front of the whole group. The students discussed the unexpected outcomes in smaller groups. Overall, teachers found that the topics of the experiments were better grasped by students in subsequent calculations and discussions.

6. Summary

We conclude from the foregoing that these experiments in geo-mechanical engineering are appropriate visualization tools for university students. The experiments are highly appreciated by the students and help to make learning more

comprehensible and clear. The discussion about the students' predictions and experimental outcomes based on the mechanical background are important for a high impact. That is to say, experiments plus discussion afterwards contribute far more to student understanding than the experiments alone. Despite the teachers' impression that the students are reluctant to participate in these experiments, the students saw their advantages and wanted them to be continued. On the basis of the evaluation, the teachers in fact decided to increase the number of experiments and—wherever possible—to follow them up with small group discussion. In order to foster the most productive discussions, however, teachers also agreed that they must first build an atmosphere of trust.

References

Herle, I. and Gesellmann, S. (2008): Demonstration experiments in geotechnical education, In Manoliu, I. and Radulescu, N., editors, Education and Training in Geo-Engineering Sciences, pp: 379–382, CRC Press.

Elton, D. J. (2001): Soils Magic, In Geotechnical Special Publication Nr. 114, American Society of Civil Engineers.

Marques, J. C. (2011): Experimental, Numerical and Virtual Tools for Civil Engineering Students, In International Journal of Engineering Pedagogy Nr. 1 Vol. 1, pp: 42–45.

7. APPENDIX: Questionnaire

Evaluation: **Portable Hands-on Experiments**

1. How much do you agree with the following statements?

		absolutely	**rather**		**rather not**	**not at all**
1.A	The experiments were a good start for each lesson.	☐	☐	☐	☐	☐
1.B	The experiments were a waste of time.	☐	☐	☐	☐	☐
1.C	I learned a lot from the experiments.	☐	☐	☐	☐	☐
1.D	The experiments were boring.	☐	☐	☐	☐	☐
1.E	The experiments were a good complement to the calculations.	☐	☐	☐	☐	☐
1.F	The experiments were superfluous.	☐	☐	☐	☐	☐
1.G	The experiments should definitely be continued.	☐	☐	☐	☐	☐

2. I LIKED:

3. I did NOT like:

4. Further comments/Suggestions for improvement: