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An example of digital field training for a diversity-friendly (and pandemic-proof) field education in geoengineering disciplines

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Abstract. Geological field training and site inspections are important components of the education in geological and civil engineering and associated disciplines. However, field training is not inclusive, does not consider students' family situations, for example associated with care work, places high demands on students' financial resilience, and therefore does not address family educational backgrounds. Also, it is not pandemic proof. Through the implementation of digital field training, students can get access to important aspects of field work in a barrier-reduced and location-independent way. Knowledge associated with geological field training therefore becomes more accessible and inclusive. Moreover, outcrops or specific rock structures that are difficult or unsafe to access in the field can be explored digitally. In this project, parts of a geological mapping course physically held in southern Germany and taught at the Faculty of Geosciences at Ruhr-Universität Bochum were turned into a digital field course. A virtual 360° tour with 3D models of outcrops and rock samples was complemented by photo, video and audio material with information on the geological setting. The digital field training was integrated via Moodle as a full lecture with H5P elements. Additionally, individual components were combined in a game engine, so that students can immerse themselves into the project settings via virtual reality experiences or on-screen. The learning outcome includes the creation of a geological map in the study area in QGIS that is complemented by a field report. The choice of equipment, procedure and results are presented. While acknowledging that a digital experience cannot fully replace the learning experience of physical field trips, it can be a valuable complement to physical field work, provide access to inaccessible geological regions, support interdisciplinary teaching projects, and provide an alternative to marginalised students who would otherwise not be able to complete a geoengineering curriculum.

1. Introduction

Geological field training and site inspections are essential components of the education in geological and civil engineering and associated disciplines. For example, students learn to describe, identify and classify soil and rock, to map and interpret geological structures, to adjust support systems and building structures accordingly, and to derive requirements with respect to their safety and durability - early during their university career - through observation of the 3D soil/rock-building-system and temporal as well as spatial interactions therein. Field training, however, may represent a barrier for prospective and actual students for which awareness in geoengineering has only recently been raised: field training is not inclusive, does not consider students' family situations (e.g. care work), places high demands on students' financial resilience (travel costs), and therefore does not address family educational backgrounds. Also, it is not pandemic proof. Furthermore, owing to a growing focus on specialised expertise and cost-saving constraints, field training is increasingly reduced and shifted to electives, which significantly reduces the quality in geoengineering education. Assignment to electives creates an educational gap and disadvantages for students who already face greater challenges, because they refrain from field training due to personal restrictions. Therefore, offering diversity-friendly field education is overdue.

Here, the example of a field training that is part of the Bachelor of Geosciences education at the Ruhr-Universität Bochum, Germany, is presented. Students take part in the geological mapping class that is physically held near Murrhardt located about 40 km northeast of Stuttgart (South German Scarplands). The equivalent digital field training comprises a virtual 3D field experience with:

- Drone videos of the geological setting and 360° photos: The geological setting is visualised, and additional information or microlectures are added at specific breakpoints. Geological features that are difficult to access or even inaccessible are visually accessible.
- 3D models of the geological structures with virtual reality visualisation: High-resolution 3D models of large-scale field views allow for the description and identification of geological features, such as formations and faults. The teaching content can be experienced both on screen and - in a particularly realistic way - via VR headset.
- 3D models of samples with Augmented Reality: Students can view high-resolution 3D images of samples, project them into their learning environment, e.g. via smartphone, and retrieve additional information.

In the following, (1) material and methods required for a recommended workflow (Figure 1) for the implementation of digital field work are presented, and (2) the potential of digital field work as a) an equivalent to physical field work for marginalised groups and b) complementary educational material for physical field work is reflected on.

The digital field training presented here is published under the creative common license and free to be adapted. It can be used as equivalent for geological field training, for the preparation or reflection of physical geological field training, as complementary material during conventional lectures, or for training of technical staff and public authorities. The authors specifically invite students and lecturers from related disciplines to collaborate on digital field training content to increase the quality and accessibility to diversity-friendly geoengineering field education.

2. Material and methods

2.1. Material - technical resources

In the following the technical resources that were required to realise the digital field programme are evaluated. The equipment presented here is neither a recommendation nor a dissuasion of technically deviating equipment.

2.1.1. Photography, video and audio. Physical presentations of teaching staff in the field were filmed with a Sony α6400. In case of light rain, a splash water protecting camera is recommended. A DJI gimbal was used to increase image stability. For high sound quality, Rhode lavaliere microphones were used together with the Rhode Go II. With this equipment, the presenter’s voice was clear also in a noisy environment, for example associated with wind, waterfalls or murmurous students, while the presenter was able to act and move freely. Video and audio material were edited and cut with Final Cut Pro for video and Logic Pro for audio. Both programmes are macOS-specific, Windows- or Linux-alternatives are available. With the help of the video editing program, material from various sources (drone footage, video footage and photos) were combined to outline the content of the lecture and to complement knowledge transfer of auditorily perceived content with visual stimuli.

2.1.2. 360° photography. H5P, a tool within Moodle, was used for the creation of 360° virtual tours. With H5P, 360° views can be linked so that students are able to digitally walk through consecutive field views. In addition to the 360° content, H5P allows the direct accessibility of video and audio content as well as 3D models of outcrops and samples which can be accessed via checkpoints (Figure 2 to Figure 4). The learning efficiency can be evaluated by tests. Passing tests can be set as a condition for successful completion of parts of the lecture or the lecture itself. H5P currently only allows to move from one 360° view to the next by a link within the 360° image. Alternative platforms, such as Roundme, also allow linking different 360° levels to each other in an overview. Furthermore, Roundme is able to display the position within an implemented map. In H5P, linking map material is currently limited to external platforms or images, but, as an advantage, H5P as a Moodle-based program facilitates content sharing among universities and is easily accessible for students. Also, the ability to post tests and summaries offers opportunities to make the course more engaging for students.

A first set of 360° views was recorded with the Ricoh Theta V, a 360° camera with two lenses and a maximum resolution of 14 Mpx. A practical feature of the camera is that it is handy and can be carried easily in rough terrain. No additional equipment is required, because a smartphone is used as remote control. The corresponding smartphone app is free of additional charges. A portable charging station, a transparent rain cover for weather-independent use and a weight for stable hold of the tripod under stormy conditions are recommended. Yet, raindrops on the cover or intense sunlight may alter image quality. A high resolution of the images is of great importance in order to depict the features of interest correctly. Details of the environment, such as rock structures, fractures and vegetation can otherwise not be clearly displayed and recognised by students. Also, the maximum distance between remote control and camera is of major relevance. A short distance for remote control is associated with visible operators and may therefore distract students or hide important details. In comparison, the Insta 360 Pro 2 has six camera lenses and a maximum resolution of 60 Mpx. The maximum remote distance could be increased to 300 m. The remote control is included, so that no additional smartphone was required. However, the equipment is larger and heavier, and may therefore be less comfortable to transport in rough terrain. Cost-benefit ratio should be carefully evaluated in advance.

The orientations of recordings at individual stops were provided with position markers on a digital GIS map. Each 360° image was marked within this map. Students can thus spatially classify their visual impression and put it into the regional geological context. Here, the software QGIS was used, which is taught as part of the geosciences curriculum at Ruhr-Universität Bochum.

2.1.3. 3D photogrammetry. 3D models were created with 3D photogrammetry. For this purpose, overlapping photos of objects were taken. The photos were translated into a digital 3D object using an appropriate program. Here, Agisoft Metashape Professional Edition was used. With the help of this procedure both, rock samples and outcrops, were digitised (Figure 2, Figure 4). The 3D models were uploaded in resolution-reduced form to the platform Sketchfab and provided as high-resolution downloads via Moodle. The models can be made accessed without having to open third party providers.

Outcrops were recorded in detail in the field. For scale, colourful ground control points were added, which can be seen from greater distance and have a defined size (here 50 cm x 50 cm). Depending on the size and accessibility, one of the two available drones or one camera was used. The local guidelines and restrictions for flying a drone must be taken into account.

The 249 g DJI Mavic has an image resolution of 12 Mpx and agile controls. The actual flight time of the drone is about 20 min per battery, additional batteries can be used to increase the combined flight time. The included controller for steering has no screen and must be paired with a smartphone. The smartphone must meet the operating requirements of the app and provide enough storage space. Charging of the smartphone and drone flights cannot be realised simultaneously. In comparison, the second drone, a DJI 4 Pro V2.0 Plus, has a remote control with an integrated display, a smartphone is not required. The life of the replaceable batteries is about 30 min. The resolution of the photos is 20 Mpx. This 468 g drone is equipped with sensors that warn of collisions. Such a system may hamper the workflow especially in forested areas with many branches in front of outcrops that activate the warning sensors. The results of the DJI 4 Pro V2.0 Plus have a high quality sufficient for the presented purpose. A result with photos taken with the DJI Mavic, calculated in Agisoft Metashape and uploaded to Sketchfab is shown in Figure 4.

Rock samples collected in the field were photographed off-site using the Sony $\alpha 6400$. Two light boxes evenly illuminate the rocks and a scale (e.g. a coin) is required for each image.

Unreal Engine is a software that allows the design of a digital 3D virtual reality with user-defined 3D models. These can be displayed in the original (maximum) resolution (unlike Sketchfab). It is possible to add audio and video content as well as gamification elements to the models. A created environment with models and learning contents can be exported as an executable file (.exe) and run with a Windows operating system. However, depending on the resolution of the models and data size of additional content, the file can reach considerable size. An additional way of experiencing the digital 3D-environment is by using a virtual reality (VR) headset. Here, the HP Reverb GQ omnicept was used. The use of VR allows the viewer a more intense VR experience than on-screen. Visual and auditory stimuli are perceived without the distance created by viewing through a screen. It allows students to climb and study outcrops in 1st person view. In order to use the VR headset, it must be connected to a PC that has a correspondingly high graphics performance.

2.1.4. Data processing. Powerful computing systems are required to process the recorded data. For the creation of the 3D models a high performance and a sufficient storage space is needed. The software is computationally very cost-intensive and the model calculation requires a lot of time and memory depending on its actual size. Outcrops can require up to several GB of storage space. Accordingly, at least 12 cores are recommended for data processing at outcrop scale. Furthermore, a 40 GB RAM and an SSD card ensured efficient swapping of files when RAM is at capacity. An RTX 3070 graphics card was installed. The duration for creating 3D models scales inversely with the computer's performance. For visualisation, a large monitor with high resolution is recommended.

For audio, video and photo editing, an Apple MacBook Air (2020) with M1 chip, 8 cores and 16 GB RAM was used. Due to the large amount of data, a correspondingly sufficient hard drive space had to be integrated. In this study, the storage is 1 TB. A large screen with realistic colour reproduction and high resolution is useful (e.g. BenQ PD2700U). The MacBook is also used with Agisoft Metashape. The performance is sufficient to calculate some of the low-quality models for the on-site quality control.

2.2. Methods – implementation

The methodological workflow presented here summarises the experiences gained from several field work periods documented for digital field experiences and is depicted in Figure 1.

2.2.1. Planning and preparation. The personnel had to be familiar with the equipment, had obtained the mandatory permits and completed training (e.g. for drone operation). Manpower was adjusted according to the required equipment and content to be produced. A minimum of two persons is recommended based on the experience presented here. Transportation of the equipment to the target area may become challenging, in particular in rough terrain where direct accessibility is limited. Equipment had to be charged and storage media was ensured to provide sufficient space.

2.2.2. Photography, video and audio. Recordings were always made with maximum technical and content quality, as post-processing reduced both. Important technical aspects included sound quality, stable video recordings in appropriate lighting conditions and aesthetic image composition. In terms of content, focus was on a sensible, comprehensible structure. It is advisable to communicate a schedule for presenters and recorders in advance. If objects were shown in detail by the presenter, they were collected and recorded separately in detail at a later stage. During post-processing, individual shots were edited so that the viewer is able to take a closer look at the object of interest while continuing to listen to the lecture.

2.2.3. 360° photography. The 360° camera was positioned so that a secure stand and a good overview of the subject of interest was provided considering lighting conditions and invisible camera operators.

2.2.4. 3D photogrammetry. For the creation of outcrop models, individual photos were overlapped by at least one third and had to be recorded at different viewing angles. For an outcrop with a dimension of about 10 m x 10 m, approximately 500 valid high-quality images were required to produce a valuable 3D model. Cloudy weather produced better image results than sunny or rainy conditions. Rock samples were photographed off-site using a scale and careful illumination and calculated to a 3D-model in Agisoft Metashape as shown in Figure 2. An in-depth high resolution can be achieved by appropriate camera settings (aperture value F8, ISO 200 - 600, exposure time /200 - /250). For a sample of about 150 cm^3 100 to 200 images were required to produce suitable results for a valuable visual inspection of the sample by students.

2.2.5. QC on-site check. The quality of the photo, video and audio material was controlled in the field and during post-processing. Photogrammetry models were calculated on-site with a low resolution to estimate the quality of the final 3D results. If the on-site quality control suggested that the footage was insufficient, recordings were repeated.

2.2.6. Post-processing. Recorded 2D and 3D material was sorted corresponding to the different stations of the field experience. The most suitable material was selected and edited. Models of outcrops and rock samples were generated using the photogrammetry software. First, a low-resolution point cloud was created to adjust relevant regions of interest. Second, a high-resolution point cloud was calculated and regions outside the objects were deleted. In a third step, a mesh (polygon count) depending on model complexity (200k to 10M vertices) was calculated. This mesh was refined, but the vertices in areas with low interest were reduced to limit file size. Holes in the models were closed and floating points (e.g. vegetation that was not completely depicted) were deleted. After the texture, whose colour had to be adjusted in most cases, was calculated, the 3D-model was exported as an .obj file. For an upload of the 3D-model in Sketchfab or in Unreal Engine, the resolution had to be reduced.

A QGIS map with contour lines, locations of the outcrops, 360°-photos and videos was created. The 2D, 3D and 360° footages were combined with the QGIS map and inserted into H5P (Figure 3). Also, field views were imported to Unreal Engine 5 to create a VR game sequence, which was exported as .exe file and can be run on windows computer or viewed by students on their home screens or at the university with VR glasses.

3. Results

The open-access digital field experience represents an interactive learning environment with VR elements and can be accessed via *http://tiny.cc/ROBX* (currently texts and descriptions in German only). The learning content is delivered in texts, videos, photos, audios, 360° views and 3D models. Virtual 3D-outcrops and 3D rock samples can be explored on-screen or via VR. A QGIS map with contour lines and information on the location of the field stations is provided to the students. The course comprises several quizzes and tests that reflect and intensify the learning outcome. After successful completion of the digital field experience, students are able to fill a geological map of the area of interest with missing information, write a short report on the geological setting and reflect their learning experience.

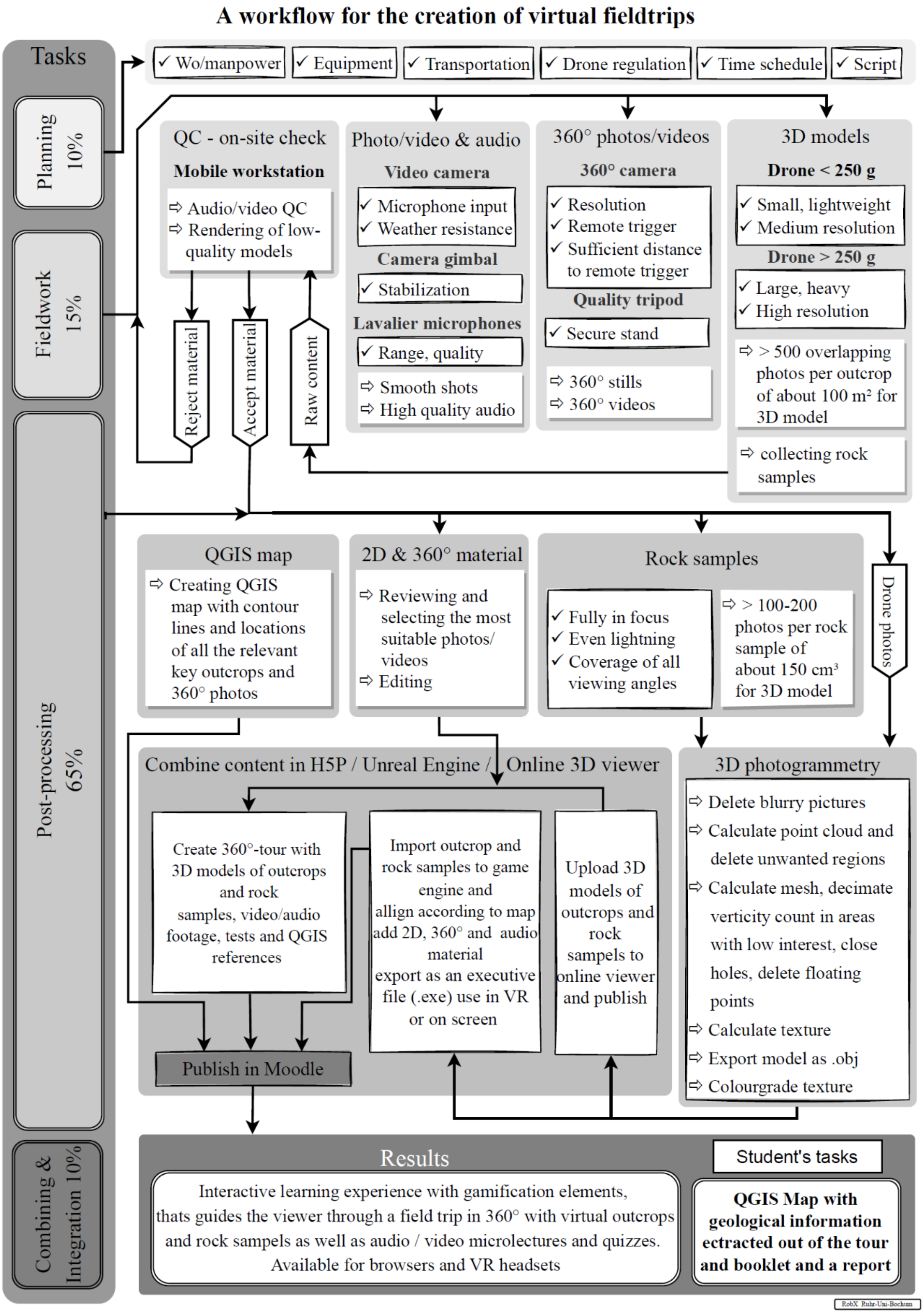

Figure 1. Exemplary workflow for conception, implementation and post-processing of digital field work.

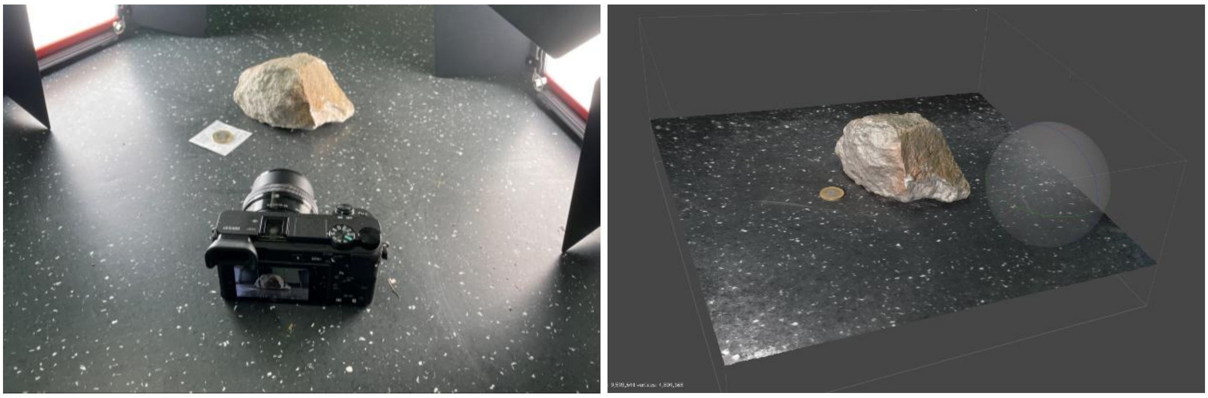

Figure 2. Image recordings of samples collected in the field. Left: photo of image recording's setup. Right: digital 3D-model in Agisoft Metashape.

4. Discussion

Provided that state-of-the-art technology with respect to image processing and 3D visualisation is available much of the professional expertise that is gained during field work can be equivalently or nearly equivalently taught using digital equivalents. In particular, through the precise visual reproduction of reality, morphological characteristics and tectonic features can be communicated. The fundamental process of analysing outcrops and rock samples can be educated. However, parts of the key teaching content cannot be covered by digital equivalents. A digital 3D-model of a rock sample cannot fully replace a handpiece, e.g. with respect to degree of cementation, hardness or haptics in general. Such information has to be provided (and cannot be experienced) in digital contents. Yet, it can be helpful as a memory aid. Also, the visualisation of reflective or transparent minerals is limited. The learning of independent orientations in the field is not achievable via digital content.

There are a couple of advantages of digital field experiences over on-site trips. On-site, large groups of students can have problems to follow the lecture in the field, e.g. in noisy environments and on narrow paths, where digital alternatives may provide a better accessibility to information. Previously inaccessible terrain or sites that are limited to number of visitors, e.g. for safety reasons, can be made available for a broader audience. Furthermore, the preparation and post-processing of a field-trip can be significantly improved and enriched by use of digital contents which complement hand-written notes, sketches in field books and memories. There is also a major potential for interdisciplinary field experiences, e.g. from site investigation to building site inspection, to providing geoengineering content to stakeholders (e.g. public authorities) and in the context of public relations.

Most importantly, digital field work equivalents represent a door-opener for students who are physically, socially or financially marginalised. Especially in light of the fact that many job profiles in geological engineering do not include direct field work, a digital experience helps to gain a profound understanding of geological and geotechnical field data, therefore opening the job field to a greater audience and increasing the number of students interested in and capable of studying rock sciences.

The cost-benefit-ratio is justified in light of the aforementioned advantages, provided that personnel and financial resources are available, in particular when considering that the initial financial effort enables multiple field projects.

5. Conclusion

In conclusion – although the digital experience cannot fully replace the learning experience of physical field trips on-site – digital field experiences can 1) provide a valuable complement to physical field work, 2) provide virtual access to inaccessible geological regions of interest, 3) support interdisciplinary teaching projects and open geoengineering content to stakeholders and interested public, and 4) provide an alternative to marginalised students who would otherwise not be able to complete a geoengineering curriculum.

Figure 3: Two field settings with additional and accessible site-specific clickable content in H5P.

Figure 4: 3D-model of outcrop. Top: distant view. Bottom: view from within the model.

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