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Teaching the relationship between topographic maps and profiles using the Augmented Reality sandbox.

Abstract

Augmented Reality (AR) tools are deemed promising for educational purposes, particularly when the tool elicits the possibility to make cognition embodied. One such tool is the AR-sandbox, which augments a dynamic topographic map onto a sandbox. The AR-sandbox might aid students in mentally picturing a three dimensional landscape from two dimensional representations. In this study, the relationship between 3D topographic maps and 2D profiles - an abstract subject which is challenging teachers and students alike- is taught using the AR-sandbox. The sample consisted of 20 randomly assigned 9th grade students from a Dutch high school. In the learning activity that was designed for this study, two students had to rebuild an environment in the AR-sandbox using topographic profiles of the environment. In this activity, the students were assigned different roles of which only one was physically engaged. The change in students' understanding was measured and analysed and the conversations between the students were examined. An increase in the understanding of students was measured; however, this increase was not statistically significant. This increase in understanding was highest for the participants who had been physically active, suggesting embodied learning. The study revealed that the learning activity was challenging but enjoyable. The AR-sandbox was perceived as an engaging tool and might be especially effective for teaching students with low spatial ability.

Introduction

When you ask people to draw a typical classroom, chances are that they would draw a teacher in front of a chalkboard and 30 students sitting behind desks, reading books and writing in their notebooks. However, this is not what most modern-day classrooms look like. Smart boards, laptops, tablets and mobile phones have made their way into the classroom. With these devices becoming more and more common in the classroom, there has been increasing interest in using these technological devices to enhance education. Based on the increasing number of scientific research in its field, one of the most promising technological developments for education in the next years is that of augmented reality (Martin et al., 2011).

Augmented reality (AR) is a technique in which a real-world environment can be seen, either directly or indirectly through a device, with additional data added to the environment in real time. This data can be as simple as numbers or sounds added to the environment or as complex as entire games taking place in the user's surroundings. According to Martin et al. (2011), AR can be used teaching any subject in which a simulation or 3D-model can support understanding. It also aids in teaching practical skills that would otherwise be very dangerous, for example in nuclear science (Eursch, 2007). Two additional beneficiary effects of AR that are especially important for teaching are enhancing learning achievement and enhancing motivation. These effects are reported by numerous studies, according to a review article by Akçayır & Akçayır (2017). Another advantage of learning in AR-environments is that it elicits a strong intention to use the AR-environment again. This intention is driven by a perceived usefulness and enjoyment of the task in the AR-environment (Wojciechowski & Cellary, 2013). An earlier meta-analysis on AR in education reported the same advantages as Akçayır & Akçayır (2017), but also mentions the limitations of AR in educational settings (Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014). According to this study, AR-systems are ineffective when the system is inconsistent in showing the augmented information. Another disadvantage of AR, that Bacca, Baldiris, Fabregat, Graf, & Kinshuk (2014) report is that the novelty of the AR-tool can distract the students from the task at hand.

An example of an AR-system is the AR-sandbox, developed by Reed et al. (2014) at UC Davis. The AR-sandbox is a small version of a common sandbox as found on almost every playground. The difference however, is that this particular sandbox has a visual layer projected on top. This layer, augmented in real time, depicts the sandbox with an elevation colour map and contour lines. This topographic map can then be altered by using one's hands to reshape the sand. The software behind this sandbox has been made open source by the developers, meaning that the software can be downloaded for free. Because of this accessibility, after a little more than a year, hundreds of AR-sandboxes have been built around the world (see figure 1). Many of these are built for science exhibitions and museums, to engage visitors in expositions. However, the AR-sandbox offers many options for use in education as well, because to gain and retain knowledge about a subject, the learner has to actively interact with the environment (Kolb & Kolb, 2005).

Figure 1. Known locations of the AR-sandbox (as of July 7, 2018)

The AR-sandbox is expected to be effective in education, because it combines visual representations with physical interaction. According to the theory of Embodied Cognition, our mind is not merely connected to our body, but our body is also shaping the mind. Therefore, to learn about a subject, we need to physically interact with the subject. This might be why AR is especially effective in teaching about abstract or invisible concepts, that cannot be made tangible otherwise (Wu, Lee, Chang, & Liang, 2013; Sayed, Zayed & Sharawi, 2011).

One such subject in which concepts cannot be made tangible is the relationship between topographic maps and topographic profiles. The abstract nature of this subject causes it to be difficult to understand for students. The AR-sandbox seems well suited to aid in this regard.

Thus, to further explore the possibilities of the AR-sandbox in education, this study aims to enquire to what extent learning about topographic maps and profiles can be supported by using an AR-sandbox.

Within this research, the main question that will be explored was formulated as:

1. To what extent can the AR-sandbox effectively contribute to teaching students about the relationship between topographic maps and profiles?

The AR-sandbox was developed as a hands-on instructional exhibit for science museums. Because of the open sourced nature of the AR-sandbox and its relatively low construction costs, it is expected that more sandboxes will be built if they prove to be useful. Already, multiple Dutch colleges have built an AR-sandbox. However, at the time of designing this study, theoretically grounded learning activities for the classroom incorporating the AR-sandbox had not yet been developed. Therefore, the first step in this research was to develop such an activity. This learning activity can then be used to further explore the benefits of learning with the AR-sandbox through experimental research.

Theoretical background

Embodied cognition

Embodied cognition is the movement in psychology that, instead of seeing our brain as a black box receiving and processing sensory input and sending motoric output, states that our body plays a central role in cognition. Conforming to this theory, the brain and body are one coherent entity interacting with the physical world; cognition may be deeply grounded in our sensorimotor processing (Wilson, 2002). A clear review of research on embodied cognition has been written by Shapiro (2010). Shapiro suggests that embodied cognition consists of three parts: the conceptualisation hypothesis, the replacement hypothesis, and the constitution hypothesis. The first hypothesis of conceptualisation pleads that the way our body is shaped, determines the way we perceive how the world is shaped. The replacement hypothesis attempts to explain the way cognition is physically embedded in our body, if not only in the brain. Finally, the constitution hypothesis discusses the possibility that our cognitive system might extend to our body or even our environment. The latter hypothesis is mainly grounded in philosophy.

The embodiment of education has showed to be effective in multiple fields. Alibali & Nathan (2012) for example, have shown that when teaching or learning about mathematics, the body is incorporated. They argue that mathematical cognition is embodied because learners and teachers use pointing gestures, representational gestures and metaphoric gestures, when explaining mathematics. Therefore, some part of reasoning and thinking about maths should be embodied. A different example comes from the field of physics education. Kontra, Lyons, Fischer, & Beilock (2015) performed an experiment on college students' learning of the concept *angular momentum*. Students who were briefly exposed to forces associated with this concept and therefore had embodied experience with the subject, scored significantly higher on the post-test than those students who did not have the physical experience.

By using the AR-sandbox, the learning activity becomes more embodied compared to using a more traditional computer simulation, where the only active part is pressing buttons on the mouse or keyboard. But, as Segal (2011) states, embodied cognition is not just physical learning or hands-on learning. The difference can be explained as follows: An experiment was done in a class of elementary students. They were asked to jump up and down whilst reciting multiplication tables. These students who were physically active showed increased learning gains, compared to the control group. However, this sort of physical activity differs from embodiment in that jumping up and down is not related to the task-at-hand, namely reciting multiplication tables. The difference is made, when the gestures that are used as inputs are congruent with the reaction of the system (Segal, 2011).

However, other research shows that observing embodiment of learning might even be as effective as enacting itself (Steffens, 2007). In this research, participants were asked to memorize certain sentences. Short sentences, such as *making clay* were used here. Participants who acted out these sentences or watched as others enacted these sentences showed better memory of the sentences than the control group participants who only learned the sentences verbally.

Augmented reality

Augmented reality (AR) is a promising tool for making education be more embodied. Before going in to detail of how AR is used in this research, AR as a concept has to be defined. Because AR is a technical phenomenon used in many disciplines, multiple definitions are used throughout articles, some more technical than others. To clarify these definitions, Milgram et al. (1995) proposed a virtuality continuum, as shown in figure 2. The virtuality continuum puts environments solely existing of physical objects on the left and an entirely virtual setting on the right (for example, a game with a virtual-reality headset). With the addition of a limited amount of virtual information added to the real environment, augmented reality is placed on the left side of the spectrum. The AR-sandbox is a physical environment, with visual data added to it, making it augmented reality.

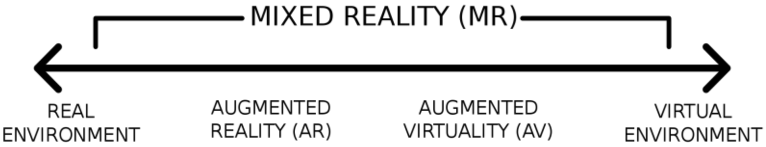

Figure 2. Virtuality continuum

AR-Sandbox

The AR-sandbox, developed by UC Davis (Reed et al., 2014), consists of a regular sandbox, above which a Microsoft Kinect 3D camera and a data projector are placed (see figure 3). The Kinect camera registers the distance between the projector and the sand or the user's hands. This data is then processed by a computer, which generates the map-image. This information is then sent to the projector. The data projector projects a visual layer on top of the sand. If the sand is closer to the Kinect camera, the colour of the sand is closer to the red end of the spectrum, whereas sand which is further away is projected with a colour closer to the blue end of the spectrum. These distances between camera and sand are grouped, with each group resembling a different colour. In between the groups, a contour line is projected. When the distance between the sand and the camera reaches a certain point, the sand is projected with a layer resembling water, making it seem as if groundwater welled up in these places. The Kinect camera also registers when a user holds their hand flat, with their fingers spread, above the sandbox. The projector then reacts with simulated rain, as if the hands were a raincloud. The flow of water over slopes, down to the lowest point is then simulated. Because the AR-sandbox is capable of showing these adjusting data layers to an environment, that can't be seen in a real-world setting, nor on paper, the AR-sandbox has possible advantages that might be used in education.

The literature review by Cheng & Tsai (2012) shows that using AR in education is the most effective

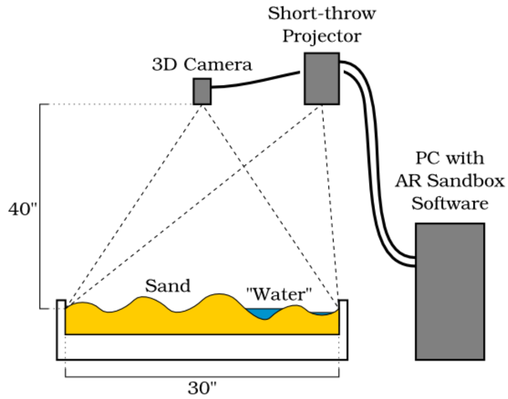

Figure 3. Set-up: (1) The Kinect scans the height. (2) The height data is sent to the pc. (3) The pc processes the data to create a map image of the sand surface. (4) The map image is sent to the projector. (5) The map image is projected onto the sand surface.

when teaching spatial ability, practical skills, conceptual understanding, and inquiry-based activities. Therefore, a topic that relies heavily on spatial ability and conceptual understanding, that is hard to teach in conventional ways, was chosen to teach with the AR-sandbox: the relationship between topographic maps and topographic profiles.

Topographic maps and the Dutch curriculum

Topographic maps are 2D representations of a landscape (see figure 4). Through contour lines or isolines, relief is displayed. These isolines are lines with a constant value of elevation above sea level. Thus, the distance between two lines represents a certain elevation. So, the shorter the distance between two lines, the steeper the slope. Often, the areas in between contour lines are coloured in, gradating from light to dark or from warmer, reddish colours to colder, bluish colours as the height fluctuates in the topographic map.

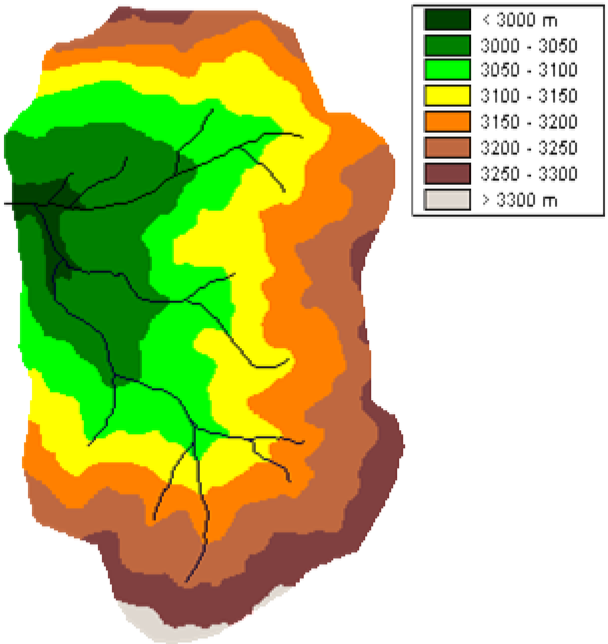

Figure 4. Example of a topographic map.

Dutch high school students learn how to read and analyse topographic maps in the 11th grade. Besides interpreting topographic maps, graduating HAVO-, and VWO-students are expected to be able to create a topographic map from geographical information (College voor Toetsen en Examens, 2016). A popular method of examining the understanding a student has about topographic maps is to let the students draw a topographic profile which is a cross-section of a topographic map. The shift of perspective from viewing from above to a 'side-view' is challenging. AR might help in this regard, because in a 3D-environment, the top-view and the side-view are two aspects of one perspective instead of two perspectives between which the students have to switch.

Moreover, by changing the sand, the profile and the map change together, removing the static view and introducing an adaptive model. Besides, according to Favier (2014), most students have trouble understanding geographical relationships. In Favier's study, geo-ICT - a term used to define all digital programs that give access to digital geographic information - was used in a classroom setting. Students who used geo-ICT had a deeper understanding of certain geographic relationships than those who followed traditional lessons, without geo-ICT. Learning with the AR-sandbox might contribute to students' understanding in a likewise form.

Interdependent cooperation

In our experiment, we decided to have two participants work in unison. However, instead of having the participants collaborate, participants have to cooperate. Although collaboration and cooperation are often used interchangeably, a subtle difference exists; collaboration is simply working together, whereas cooperation signifies interdependence between the participants. Therefore, cooperative learning can only succeed if both participants carry out their tasks. Interdependence is usually established by assigning different roles to students, as is the case in this experiment. According to a review article on cooperative learning theory, cooperative learning induces, amongst other advantages, higher achievement, better reasoning and increased task enjoyment (Johnson & Johnson, 2009). In addition to separating the students in different roles, the students are physically separated, although they are still able to hear each other. This ensures that all communication has to be verbal, which forces the students to communicate clearly. We expect that having to think about clear communication adds to the advantage of better reasoning, as proposed by Johnson & Johnson (2009). A positive side effect of having the participants communicate solely verbally is that this makes analysis of the conversations more straight-forward as no ambiguous communication in the form of gestures or body language can exist. However, by assigning different roles, we are excluding one role from being physically active. As this would deny one of the participants from the advantages of embodied learning, the experiment is thusly designed that both participants carry out both roles throughout the experiment. Further explanation on these roles will be given in the methods section of this article. More design-choices based on literature are hereafter explained.

Model for AR-research

To make the design of this research be more thoroughly grounded in theory, '*six precepts to drive forward an MR research paradigm*' were applied in designing the experiment (Lindgren & Johnson-Glenberg, 2013). Lindgren & Johnson-Glenberg, two experts in the field of research on emerging media platforms, wrote these six precepts to reinforce the efficacy of empirical studies in an MR-environment. Although these precepts were especially designed for embodied learning in Mixed Reality - and as formerly explained MR and AR occupy slightly different places on the virtuality continuum - we found that these precepts were applicable to embodied learning in AR as well.

The 1st precept states that the physical benefits of embodied learning should be ascribed to all participants. As the theory of embodied cognition states that physical stimulation adds to learning, all students should be physically engaged to be able to learn. In accordance with this precept is the research of Jang, Vitale Jyung, & Black (2017). According to their study, students manipulating an anatomical structure in a 3D Virtual Reality anatomy lesson were more likely to successfully replicate this anatomical structure than students who only perceived another student performing in this anatomy lesson. Although this is in contrast with the earlier mentioned research by Steffens (2007), which showed that perceiving embodied learning may be as effective as embodiment itself. However, neither of these contrasting studies suggests that viewing is more effective than participating. Thus, if the physical manipulation of the sand in this learning activity shapes the understanding of the participants, then all participants should be given the chance to be physically active; this was one of the previously mentioned arguments for having all participants execute both roles throughout the experiment. Furthermore, to ensure that all participants are equally active, -which allows for reliable comparison afterwards- the experiment has a limited timespan over which a participant is active.

The second precept is to assert action-concept congruencies. This entails the idea that embodied cognition is more effective when the physical action in the altered reality environment is more congruent to the theoretical concept that the action represents. This precept confers with the formerly mentioned research of Segal (2011). An example from a lesson by Lindgren & Johnson-Glenberg was given to support this precept. In a lesson on gear rotation in which the input was bodily movement, students were instructed to use their stretched arm rotating from the shoulder as input to a rotating gear instead of moving their arm forward and backward as input. Rotation of the arm mimics the rotation of the gear more congruently than moving forward and backward. This should increase the effectiveness, as the theoretical concept is intertwined with the physical concept.

The 3rd precept of Lindgren & Johnson-Glenberg declares that augmentation should augur well, meaning that AR should not just be a digital replica of reality. AR should enhance reality or be able to bring students in an environment which cannot be explored in reality. The AR-sandbox adds information on height to a regular sandbox in real-time, which cannot be achieved in a regular sandbox. Therefore, this research adheres to the 3rd precept.

Lindgren & Johnson-Glenberg's 4th precept states that opportunities for collaborative learning should be introduced. Since two students are working together on the assignments, collaboration is ensured.

Lindgren & Johnson-Glenberg's 5th precept states that lab studies should be combined with real-world implementations. In this study, we were unable to comply with this precept.

The sixth and last precept advises to re-envision assessment. Lindgren & Johnson-Glenberg find that studies on MR-research often assess the effects of MR with traditional non-constructivist tests. Certain effects of embodied learning environments that are not measured with traditional tests might be detected when the assessment is as close to the assignment as possible. This precept recommends using new, creative measures and methodologies.

With these precepts in mind, the experiment of this study was designed around the first question, as mentioned before:

1. To what extent can the AR-sandbox effectively contribute to teaching students about the relationship between topographic maps and profiles?

The separation of participants into interdependent roles led to the second question of this study:

2. What is the influence of assigning different roles to students during the collaborative processes?

To investigate what challenges students are experiencing in learning about topographic maps and profiles and to discover how AR can help to relieve these students from these difficulties, the conversations of the students are more thoroughly examined. This led to the third research question of this study:

3. To what extent do dialogues between students indicate insight into the process of recreating a landscape?

Methods

Participants

The set-up of this experiment is shown in figure 5. Twenty 9th grade students, aged 13 to 14 years old, randomly selected from six different classes of the same level of the College Nassau Veluwe participated in this experiment. For this study, 9th grade students were chosen because they had not yet learned about topographic maps and profiles but will be doing so later on in this grade. As per the design of the experiment, the participants worked together in pairs, yielding 10 pairs and therefore 10 trials. One research trial lasted 50 minutes, as this is the duration of one lesson in most Dutch secondary schools.

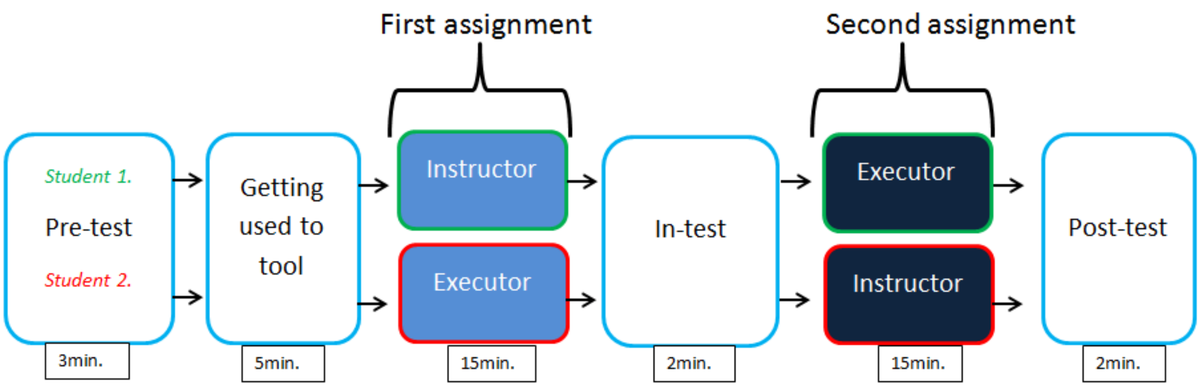

Figure 5. Flowchart of the experiment.

Design of the experiment

Prior to the learning activity, a pre-test was carried out to measure pre-existing understanding of the relationship between topographic maps and topographic profiles. This pre-test is explained in detail further on in the data collection section.

After the pre-test, the participants were shown how the AR-sandbox functions. They were then allowed to play around with the sandbox for 3 minutes, before continuing to the learning activity. The pre-training principle by Mayer (2002), states that this increases effectiveness of the task afterwards. Mayer argues that getting used to a tool helps to create a mental model of the tool, after which more cognitive capacity is available to be dedicated to the learning activity.

The learning activity was designed around the AR-sandbox and focuses on the relationship between topographic maps and profiles. For the initial development of the learning activity, five experts were consulted. Three of which were geography didactics professors and two experts were physical geographers. Along with the advice of these experts in the field, the aforementioned precepts of Lindgren & Johnson-Glenberg (2013) were applied.

The learning goals of the activity were:

- The students have a deeper understanding of the relationship between topographic maps and topographic profiles.
- The students are able to recreate a landscape in 3D in the AR-sandbox from given topographic profiles.

As the second learning goal shows, the learning activity involved the participants receiving topographic profiles of a landscape and then trying to recreate said landscape. Using AHN-viewer, an online interactive map of the current landmass elevation levels in the Netherlands, topographic profiles can be constructed along a line in the map. Using this tool, two equal-sized rectangular portions of landscape were selected, with enough elevation to be interesting for this learning activity. In these landscapes, three topographic profiles have been drawn over the width of the rectangular environment.

In the learning activity two students are working together with one student, hereafter called the *performer*, manipulating the sand in the sandbox and the other student telling him/her how to do so, called the *instructor*. Some *performers* might prefer to shape the sand with a small shovel or other tool as to not get their hands dirty. However, to maximize action-concept congruencies (Lindgren & Johnson-Glenberg's 2nd precept), students were obligated to use their hands. For AR to be effective there should be congruence between the physical action of the student and the corresponding reaction of the system. The input to the sandbox is merely moving the sand; not much altering could take place in this regard. However, by making sure the participants use their hands, they will feel the slopes and curves of their creations which might contribute to their comprehension.

As explained earlier on, the two interdependently cooperating participants are separated by an opaque screen (see figure 6). Therefore, all communication between the participants is verbal. However, the *instructor* will be able to see what the *performer* does with the sand in the sandbox on a monitor on the *instructor's* side of the separating screen, which shows the projected image of the beamer. Because of the physical separation and separation into different roles, the design now meets the 4th precept by Lindgren & Johnson-Glenberg: 'introducing opportunities for collaborative interactions'.

The *instructor* will receive the instructions for the assignment, along with the map of the landscape with the corresponding topographic profiles, which the *performer* has to recreate in the sandbox. These materials can be found in Appendix B. Beside the three topographic profiles, the map only shows some elementary features of the landscape, such as the names and locations of towns and rivers. Thus, the map is not a topographic heat map with contour lines. The *instructor* has to derive the 3D landscape along the lines of the topographic profiles. To help the *performer* and *instructor* understand each other's position relative to the sandbox, a few cues have been placed in the sandbox. First-off, the *instructor* has the cardinal directions added to the screen and the *performer* has the cardinal directions placed on the sandbox. Secondly, two skewers, labelled with the names of two villages are placed in the sandbox, one in the outmost north-eastern corner and the other in the south-western corner. The *instructor* knows the location of these places as well, because they are marked on the map, which is explicitly mentioned by the researcher.

The researcher states that the participants have 15 minutes to execute the assignment and states that he will not be assisting them from this point on. After every 5 minutes, the researcher will tell the students how much time is left.

When 13 minutes have passed, the researcher asks the students whether or not they have thought about recreating the landscape in between the topographic profiles. This is done to ensure that the students have thought about this and therefore have the possibility to do this, since their result is partially scored on this aspect.

After 15 minutes, the assignment is ended and the researcher will show the students the actual current heat map of the elevation of the environment. This will be compared to their result, so the participants can reflect on their work.

Hereafter, the students perform in a test similar to the pre-test, called the in-test.

Following the in-test, the participants performed in a second assignment in which the former *performer* now took on the role of *instructor* and vice versa. This is done to heed the advice of Lindgren & Johnson-Glenberg's 1st precept, which advices to ascribe the body-based learning benefits to everyone.

The instructor will receive new materials of a different environment. Skewers with the names of two new villages will be placed in the sandbox as cues for the *performer* and the second assignment can commence.

After a maximum of 15 minutes, the assignment ends. The result will again be evaluated by comparing it to the current elevation profile.

Following the evaluation, a post-test is conducted to assess the learning gains of the participants.

An earlier design was tested in a pilot, after which minor adjustments were made to the materials and instructions. From this design, a task analysis was derived, to be used in the data analysis of this study.

Figure 6. Experimental set-up: students are separated by an opaque screen.

Data collection

In the experiment, three types of data were gathered. First off, three tests were done to measure the conceptual knowledge of the students at three different points in time. According to Lindgren & Johnson-Glenberg's 6th precept, these tests should be as close to the AR setting as possible. Although we were not able to make the test in AR, we did use photographs of the AR-sandbox, to be as close to the AR as possible. The tests consisted of six photographs of different landscapes, build in the AR-sandbox. On these photographs, a line was drawn from point A to point B. The participants then received six topographic profiles between two points, A and B. They were then asked to match the profiles with the corresponding lines on the photographs. To assure that all students knew in what way topographic profiles are constructed from topographic maps, a short written explanation was added to the pre-test. The explanation, maps and profiles used in the tests can be found in Appendix C. The first of these three, the pre-test, was done prior to the designed learning activity to examine the students' pre-existing understanding of the relationship between topographic maps and profiles. In between learning activities another test was given (called the in-test in figure 5) and following the second learning activity a post-test will be done. The in- and post-tests were done to determine change in understanding of aforementioned relationship between topographic maps and profiles. Due to limited time, the participants received 2 minutes per test.

Secondly, audio-data of the spoken communication between the students was recorded alongside video-data of the continually changing sandbox. The students were separated by an opaque screen. This way, all communication had to be verbal, which allowed for more accurate analysis afterwards.
The third data-type consists of the results of the learning activity, which was rated on a 10-point scale.

Analysis

To get a general sense of learning gains due to the learning activity, pre- and post-test data were compared.
The in-test data was compared to both pre- and post-test data, to assess the influence of the switching of roles within the experiment and to evaluate the impact of the order in which the roles were occupied.

The audio recordings were used to analyse the discussions between the students. The coded speech data was compared to the task analysis. This comparison displays whether the students followed a logical order of actions within the learning activity. These findings were then compared to the rated results of the learning activity. This shows the relationship between the order of actions and the actual outcome of the activity. We expected to find that following an order of actions more similar to the task analysis would yield better results in the learning activity.

Camera footage of the sandbox projection was used alongside this audio footage, to compare the communication of the students to the physical adjustments in the sandbox to help clear-up ambiguous lines of conversation.

Results

Due to time shortage during the experiment, out of 20 students, four students were not able to do the post-test. Therefore, the test-results of the remaining 16 students were used in analysis. The time limitation of 2 minutes per test was sufficient in all but 1 of the 56 executed tests.

First, the effectiveness of the designed activity to convey the relationship between maps and profiles will be examined. This learning activity might have increased the students' understanding of the relationship between topographic maps and topographic profiles, since the average score on tests did increase from pre-test to in-test to post-test (see figure 7).

	N	Minimum	Maximum	Mean	Std. Deviation
Pre-test	20	0	5	2,75	1,773
In-test	20	0	5	2,80	1,735
Post-test	16	1	5	3,56	1,209

Figure 7. Descriptive statistics on tests.

However, a Wilcoxon signed-rank test showed no statistically significant change in scores between pre- and post-test, Z = -1.528, p = .127, pre- and in-test, Z = -0.057, p = .954 or in- and post-test, Z = -1.,080, p = .280. Next, the connection between performing in the tests and performing on the learning activity was explored. Therefore, the resulting landscape of the learning activity was graded on a 10-point scale. Scores ranged from 0 to 5 (average of 3.2) on the first assignment and from 0 to 9 (average of 4.6) on the second assignment. The averages of the two scores on the two assignments per duo were then assigned a rank from 1 to 8. These ranks were compared to student-pairs' average of scores on the pre-, in-, and post-test. Again, these averages were assigned another rank. Thus, the ranks of performance in the tests were compared to the ranks in results in the learning activity with a Spearman's signed rank test. This showed to be significantly correlated, r(8) = .758, p = .029. Furthermore, the assignment proved to be very effective in retaining the attention of the participants. Of all the remarks made by the participants, only 1.7% was not related to the task. And although no formal survey was executed, the researcher asked students for their opinion on the activity. The most duos referred to the activity as being "Fun, but also hard to do". Some students mentioned that they would like to have the sandbox incorporated in their classrooms.

Secondly, this study examined the effect of assigning different roles to participants during the learning activity. To do so, results on the three tests were compared between *instructors* and *performers.* After the first assignment, the average scores of *performers* had increased (2.5 to 3.1), whereas the average scores amongst *instructors* had decreased (3.0 to 2.5). After the second assignment in which the roles were changed, the new *performers (*former *instructors)* increased their average score from 2.5 to 3.6 whilst the new *instructors* increased scores from 3.1 to 3.5. Although these increases in score for performers were higher than average, no significant results were found regarding this possible connection.

As was mentioned before, the average scores on the two assignments of the learning activity increased from 3.2 to 4.6 (on a 10-point scale) after role swapping. One factor contributing to this increase is that after role swapping, the *instructor* now understands what the *performer* needs to hear to perform well. The next quote shows an *instructor* having trouble trying to explain herself:

Quote 1, MOV084, 10:24 - 11:58

Instructor: And the mountain in the south… in the north-west.
Performer: Yes, this one?

Instructor: Yes. It may, like... there's no mountain in the south-west, but it has to go down, flowing. Like diagonally downwards, to the south.
Performer: Like this?

Instructor: Yes, there. And then it has to go diagonally downwards, you know, like a… okay, i don't think you understand me. Ehmm. No, like that, you're going east. To the south. To south. And then, not… no… how am I going to explain this? -pause- Yes! The mountain has to stay the same height, so take some sand from the north. Like, from where it has to be level ground. And then you put it a little, like… you know how a tri…. hmm, no…. and then *you have… it goes… It's not a steep mountain! It's a not steep mountain and then to the south.*

This excerpt shows a participant getting stuck, trying to explain that the mountain gradually diminished in height. After swapping roles, the new *instructor* uses clearer wording, as quote 2 illustrates:

Quote 2, MOV084, 16:05 - 16:22

Instructor: Yes, it has to be a bit bigger, so put some more sand on it. And then it goes abruptly downwards, so it goes sharply.
Performer: Okay.

Instructor: So it is very high and then suddenly very low. You could compare it to a ravine.

There is no reason to assume that this focus on more clear wording is solely caused by the bad experience in the first assignment that is shown in quote 1. However, it is exemplary of how many of the conversations changed after the switching of roles.

Finally, to gain insight into the process of recreating landscapes, the conversations of the participants were analysed. Audio data of the conversations during the assignment was live coded from audio without transcription to text format. All data was coded by the same researcher. A total of 3167 coded segments were thusly obtained. No significant differences between absolute or relative amounts of specific codes were found, between better and lesser performing duo's, except for lesser performing duo's more frequently stating that they were confused. To further compare these conversations, a task analysis was made after a pilot of the learning activity. This task analysis is shown in figure 8, of which an extended explanation of the individual steps can be found in Appendix A.

#	Step	Description	Time
1	Pre-test	Matching maps and profiles	3’
2	Getting used to tool	Researcher shows how AR-sandbox works. Participants interact.	5’
3	Instruction of assignment	*Instructor* conveys assignment to *performer*	1’
4	Orientation on partner’s perspective	*Instructor* is learning the *performer’s* perspective	1’
5	Interpreting map and profiles	*Instructor* interprets the received maps and profiles	1’
6	Creating 1st profile	*Instructor* explains how the 1st profile should look, *performer* creates it.	4’
7	Creating 2nd and 3rd profiles.	Ditto to step 6, with profile 2 & 3.	5’
8	Refining profiles.	Rough profiles are refined.	2’
9	Connecting profiles	The 3 profiles are connected to form 1 environment.	1‘
10	Evaluating results	Evaluating profile by comparing to actual map of the environment.	1‘
11	In-test	Ditto to pre-test.	2‘
12	Role swap	*Instructor* takes on role of *performer* and vice versa.	1‘
13	Repeating steps 2 through 8	New *instructor* receives materials and steps 2 through 8 are repeated.	15‘
14	Evaluating results	Evaluating profile by comparing to actual map of the environment.	1’
15	Post-test	Ditto to pre-test	2‘

Figure 8. Task analysis

A vital step in the task proved to be step *4: orientation on other’s perspective*. When this step was skipped or when participants failed to orientate on their partner’s perspective, successive steps most often failed likewise. A Mann-Whitney test indicated that the scores of duo’s succeeding this step was higher (Mdn = 4.5) than that of duo’s skipping or failing this step (Mdn = 1), U = 10.5, p = .003.

Although in the task analysis this step is only mentioned at the start of the learning activity, most participants had to re-orient on their partner's perspective during the assignment. Some participants, who were aware that their 'left' was not their partner's 'left' and therefore used unambiguous phrasing, were able to communicate more clearly. Quote 3 illustrates this:

Quote 3, MOV086, 12:03 - 13:05
Instructor: There's a river to the left side… bottom.

Performer: Left, yeah...
Instructor: Ehhh, north.

Performer: North. Okay.

Instructor: And it runs all the way to the right side.
Performer: Right side?! What use is that to me?

Instructor: Oh, to the south. South.
Performer: Okay.
Instructor: So, from the north it meanders to the south.

Most of the time-on-task was spent creating and adjusting profiles (steps #6 through #9 and #13). To analyse participants' conversations in these steps, the sequencing of coded segments was analysed. To do this, for every coded segment, the successive segment was reported, resulting in as many sequence notations as there were coded segments minus one per conversation. Derived from these numbers, the codes below show a typical conversation during creation of a singular profile.

Typical conversation, derived from most recurring codes in sequence:

1. *Instructor directs performer to new location.*
2. *Performer checks location.*
3. *Instructor acknowledges location OR adjusts instruction on location.*
4. *Performer either:*
    a. *acknowledges location.*
    b. *checks location (back to 2).*
5. *Instructor encourages performer to construct (part of) profile.*
6. *Performer acknowledges instruction OR asks for clarification.*
7. *Instructor either:*
    a. *waits for construction to be completed.*
    b. *gives clarification (back to 5).*
8. *Performer inquires whether or not construction suffices.*
9. *Instructor either:*
    a. *approves of construction (continues to next location with 1).*
    b. *adjusts his instructions on construction (back to 5).*

In order to compare the actual conversations, relative proportions of sequences were calculated and compared. These sequences showed little quantifiable differences between better and less performing participants. Except for that in well performing couples' conversations, the *performer* more often replied to the *instructor* - when being directed towards a location in the sandbox (code 1 in example) - with an acknowledgement (code 4a) or a question to check if they understood correctly (code 4b).

The following, quote 4, exemplifies this:

Quote 4, MOV085, 17:53 - 19:15

Instructor: Ok, then you have to, let's see, to the east make it very low again.
Performer: Again, just, let's say from the mountain?
Instructor: Yes
Performer: Is this good?
Instructor: Yes. And then again from the very tall mountain to the south again very low.
Performer: Like this?
Instructor: Yes. Then again completely on the other side at the south in the corner, very high.
Performer: Like, about this?
Instructor: Yes. And then if you, from the mountain in the south to the north. From the mountain to the south you have to go to the north again, like from the very tall mountain you have to make it a bit yellow and then in the middle blue again.
Performer: Like this?
Instructor: Yes.

However, when the sequence of statements differs from the typical conversation as shown above, miscommunication often arise. As shown in quote 5, where the instruction for construction precedes the direction to the new location, communication fails:

Quote 5, MOV08A, 19:57 - 21:35

Instructor: Then, you must have a transition, so it goes down but stays a bit high, to the south.
Performer: A whole row?
Instructor: No, not a whole row. You know, a bit low… like I had to do. A bit low and then a bit convex, you know, like that. A… a stripe.

[interruption because of technical problem]

Performer: So, you have to not make it entirely green-yellowish, but make it a bit higher.
Instructor: What, here?
Performer: A line from north to south on that height
Instructor: At what height?
Performer: Of the small mountain.
Instructor: Of the whole mountain, should the entire line be...
Performer: No, not that height, at the height of east to west.
Instructor: Oh, that line. Just say so.
Performer: Yes, that line! Should I explain everything to you in degrees?!
Instructor: Well, would be fun. -pause- Okay, is this all right or should it be higher?
Performer: Amanda, it should be a line. There's still too much greeeeeen! It should be yellow.
Instructor: More yellow?
Executor: Yes, on the whole line, from north to south. At the spot of the little mountain.

Conclusion

This study aims to enquire to what extent learning about topographic maps and profiles can be supported by using an AR-sandbox. To do so, the following questions were explored:

1. To what extent can the AR-sandbox effectively contribute to teaching students about the relationship between topographic maps and profiles?
2. What is the influence of assigning different roles to students during the collaborative processes?

3. To what extent do dialogues between students indicate insight into the process of recreating a landscape?

To answer the first question, the conceptual knowledge of participants was measured before, during and after the learning activity. The scores on these tests correlated with the performance in the activity, which contributes to the validity of the tests. The results of the participants on these tests increased on average over the course of the learning activity, albeit no significant difference between understanding before and after the learning activity was found. Therefore it is unsure whether the learning goal of the learning activity that corresponds with this research question, *"The students have a deeper understanding of the relationship between topographic maps and topographic profiles"*, was accomplished. The second learning goal of the learning activity was formulated as: *"The students are able to recreate a landscape in 3D in the AR-sandbox from given topographic profile".* This goal was achieved by most pairs of students, but not all. All but one pair of students retained or increased their score on the second assignment, compared to their score on the first assignment. Remarkably, one pair of students who completely misunderstood the assignment and scored 0 out of 10 on the first as well as the second assignment both increased in scores on the tests. Although they scored very low on the assignment as they did not understand what was expected from them, they did have 30 minutes of experience in thinking about the relationship between topographic maps and profiles, 15 of which was physical and perhaps embodied experience. This may have led to an increase of understanding which is reflected by the tests, although the possibility that these students scored higher on the successive tests by sheer luck should not be excluded.

One underlying factor, contributing to the variance between the participants scores on tests and on the assignments is possibly the variance in spatial ability. According to Black (2005), college students with lower spatial ability experience more difficulties in interpretation of topographic maps than those with greater spatial ability. On the other hand, according to multiple studies, AR is an effective tool in increasing spatial ability. An example of such a study is that of Martín-Guitérrez et al. (2010). They designed an AR book, called AR-Dehaes, which simulates 3D-models to help students visualize these models, which are otherwise presented from different perspectives in 2D. This increased their spatial ability over a short time-span of less than 10 hours. These findings of Black (2005) and Martín-Guitérrez et al. (2010) suggest that students who have lower spatial ability scores would benefit most from learning with the AR-sandbox.

Although it is unclear whether or not participants' knowledge increased, it was clear that the learning activity was effective in retaining the attention of students. One factor in retaining attention might be the difficulty the students experienced in performing in the experiment. According to a large-scale study by Goldhammer et al. (2014), individuals spend more time on a problem solving task, when the difficulty increases. Another influence may be the semi-experimental setting. Although the experiment was conducted in the students' own school, working under the supervision of a researcher might influence the effort the students put into their work. However, possibly the most probable cause of retaining attention was the use of the augmented reality tool. As, amongst others, Liu and Tsai (2013) have shown before, AR can be effective in raising engagement of which retaining attention is a part. In the rarely occurring moments that the attention of the participants dwindled from the assignment, it was mostly due to something happening in the sandbox. For example, students would see their hand being measured and projected in the sandbox, when they left in in the same place for a while. This distracting behaviour was mentioned as a possible limitation by Bacca, Baldiris, Fabregat, Graf, & Kinshuk (2014). The other possible limitation that was mentioned by their study was that AR is not effective when it is inconsistent in showing the added digital information. As the AR-sandbox projects the augmented layer in real-time, this was not a problem. Moreover, in agreement with many of the mentioned articles in the review by Akçayır and Akçayır, which state that AR enhances enjoyment and provides a positive attitude, participants said to have fun in the assignment. Others stated that they would like to have the AR-sandbox integrated in their lessons, which is in accordance with Wojciechowski & Cellary's (2013) notion that having fun with the AR tool elicits a motivation to use the tool again.

To answer the second question, the influence of assigning different roles to participants and switching roles seemed to have some impact on the process. One remarkable result was the increase of scores on tests after participants took on the role of performer. This would suggest that shaping the sand had a bigger influence on understanding the relationship between topographic maps and profiles, than reading maps and profiles and conveying their embedded information did. This increase of understanding by physical manipulation is in accordance with the embodied cognition theory. However, this minimal increase in test-scores cannot be assigned to the switching of roles, because no significant differences were found.

Moreover, switching roles halfway through the exercise gave the participants insight in their partner's situation. This led to instructors giving more clear instructions, since they knew what useful information to receive was. The performers started asking more questions to help out the instructors, because they knew what challenges the instructors endured.

The third and last goal of this study was to gain insight into the process of recreating landscapes in the AR-sandbox. To explore this process, the conversations between the cooperating participants were compared to the task analysis that was made, based on the pilot of the experiment.

This comparison showed that the '*orientation on partner's perspective'* step of the experiment is crucial to the outcome of the assignment. To assist the instructor in this step, a compass rose was added to the maps and profiles. On the border of the screen, on which the instructor had a live view of the state of the sandbox, the cardinal directions were added as well. To help the performer with orientation, the cardinal directions were added to the borders of the sandbox. Another cue was added to the sandbox in the form of the names of two villages on skewers placed in their correct locations. These villages appeared on the map of the instructor as well. This fact was mentioned by the researcher prior to each assignment. Although plenty of cues were available to help the participants orientate to each other's perspectives, for some participants, this step remained challenging. This may have been caused by the orientation of the map relative to the orientation of the sandbox. On the map, north was oriented upwards, whilst the sandbox was oriented so that the point furthest away from the performer was east. The screen on the side of the instructor was placed vertically, so the side of the sandbox that was east was directed upwards on the monitor. Therefore, the instructor had to physically or mentally rotate the map with the topographic profiles to have the map and the screen in corresponding orientations. One duo did not rotate the map for both assignments and their final results were scored 4 and 5 out of 10. This was possible, because their result was quite similar to the actual environment, except for it being turned a quarter turn. Another duo however, started off with their map being turned as well, but halfway through the assignment, the instructor made use of the 2 villages that were placed in the sandbox. This led to misunderstanding of the orientation of the maps and the profiles. This resulted in a lot of miscommunication and a final product with a score of 1 out of 10. The easiest way to fix these problems for this assignment is to make 'forward' in the sandbox or 'upward' on the screen congruent with 'north'. As maps are almost always presented with 'north' being 'up', this would probably diminish miscommunication. However, by doing so, the possibility to learn that north is not 'up', but relative to you position on earth would be denied.

After orientation, the actual construction of the profiles could commence. In this phase, two aspects were important. First off, the chosen terminology seemed to matter. This is comparable to the orientation step, in which the more precise 'north' was more useful than the inaccurate 'up'. Quote 3 showed that inaccurate language from the instructor caused frustration with the performer. Besides frustration, unclear communication also led to less well constructed profiles. And in the example of quote 5, it took the instructor more than a minute and a half, to convey a relatively easy command, because of the unclear phrasing combined with the wrong order of instructions. This order of instructions is the second important aspect to effective instructor behaviour. The first instruction should be focused on directing the performer to the correct location. This information should be given separated from any information on the construction. This way, the performer has the chance to check the location, until the performer and instructor are certain that the location the performer is going to construct in, is the correct location. The performer can place his/her hands in the corresponding location and wait for the next advice, on construction. The sequence of these two parts of information is important, because the performer can hardly do anything with the construction information, until he knows of the location in which to do this. Therefore, when the construction advice precedes the location information or is offered simultaneously, miscommunication often occurred. Well performing duo's ensured that every bit of information was received and processed, by asking for acknowledgment and asking question to check if they understood correctly.

To aid students in this learning activity, emphasis on precise terminology could be provided by a teacher, as for most students communicating clearly was the most difficult part of communicating without seeing each. However, constructivist learning theories would argue that learning is more effective when students discover what language is effective without help. Moreover, one of the challenges of implementing the AR-sandbox in the classroom is that only a few students can effectively work together simultaneously. Organisational difficulties would arise when the teacher is required to aid these students in performing the learning activity. The learning activity can more easily be incorporated into a lesson, when the students working with the sandbox work independently from the teacher. One could argue that this problem of the teacher dividing their attention between a few students working with the sandbox and the rest of the classroom working on another assignment can be solved by having all students work on a computer simulation. Many of the benefits of AR can be achieved by using computer simulations, including improved understanding of abstract scientific concepts (Rutten, van Joolingen, & van der Veen, 2012). Furthermore, in most classrooms computers are widely available; this makes computer simulations an accessible tool. However, the AR-sandbox offers distinct advantages that cannot be achieved in computer simulations. First, in contrast with typical computer simulations, the AR-sandbox elicits embodied learning. Secondly, the AR-sandbox needs barely any instruction or time to learn the tool, which is not the case for most computer simulations. An easy to use digital learning system does not only save time in the classroom, it affects educational effectiveness as well, according to Sun, Tsai, Finger, Chen, & Yeh (2008). Third, the AR-sandbox can be applied for teaching multiple subjects, such as hydrology, environmental studies and geography. This is in contrast with computer simulations which are generally only suited for one task. Other advantages of the AR-sandbox -which are not in contrast with computer simulations, but does add to the usefulness of the AR-sandbox- are its low production cost, accessibility of the software due to its open-sourced nature and the extensive online community of users and developers of AR-sandboxes around the world. Although placing such a large tool inside a classroom or school laboratory might be a challenge, the beneficial effects on learning and motivation should justify its placement in any school.

To summarize, the learning activity was perceived as challenging and most students enjoyed participating in the study. More importantly, the results of this study suggest that the AR-sandbox is an engaging tool and may enhance understanding of the relationship between topographic maps and topographic profiles. However, further research with a greater number of participants should indicate whether the positive findings of this research are coincidental or applicable to the population. Explorative research on using the AR-sandbox in a geology college course shows that the AR-sandbox can effectively be incorporated in a course (Woods, Reed, Hsi, Woods, & Woods, 2016). Moreover, Woods, Reed, Hsi, Woods, & Woods found that students are overwhelmingly positive in their perception of the learning benefits of the AR-sandbox. However, no comparative research between traditional methods and teaching with the AR-sandbox has yet been done. In the future, comparative research could be done to indicate whether the learning activity as designed in this study exhibits its proposed benefits over traditional methods of teaching the relationship between topographic maps and profiles.

We argue that acting out the role of performer may be especially useful, since this is the phase in which embodied learning takes place. To support this claim, additional research could be executed in which a control group observes the activity but does not partake in it.
Another direction for future research is to distinguish between students with higher and lower spatial ability, as AR seems to be especially beneficial for the latter group.

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Appendix A: Task analysis

#	Step	Description	Time
1	Pre-test	Matching maps and profiles	3’
2	Getting used to tool	Researcher shows how AR-sandbox works. Participants interact.	5’
3	Instruction of assignment	*Instructor* conveys assignment to *performer*	1’
4	Orientation on partner’s perspective	*Instructor* is learning the *performer’s* perspective	1’
5	Interpreting map and profiles	*Instructor* interprets the received maps and profiles	1’
6	Creating 1st profile	*Instructor* explains how the 1st profile should look, *performer* creates it.	4’
7	Creating 2nd and 3rd profiles.	Ditto to step 6, with profile 2 & 3.	5’
8	Refining profiles.	Rough profiles are refined.	2’
9	Connecting profiles	The 3 profiles are connected to form 1 environment.	1‘
10	Evaluating results	Evaluating profile by comparing to actual map of the environment.	1‘
11	In-test	Ditto to pre-test.	2‘
12	Swapping roles	*Instructor* takes on roll of *performer* and vice versa.	1‘
13	Repeating steps 2 through 8	New *instructor* receives materials and steps 2 through 8 are repeated.	15‘
14	Evaluating results	Evaluating profile by comparing to actual map of the environment.	1’
15	Post-test	Ditto to pre-test	2‘

Pre-test:

Participant reads theory on how topographic profiles are derived from topographic maps. Participant then receives 6 maps and 6 profiles and has to match corresponding maps and profiles.

Getting used to tool:

Researcher shows how the AR-sandbox works. Students get to interact and get a feeling with the tool.

Instruction of assignment:

Researcher explains that *instructor* receives an assignment. He tells the *instructor* that he will place 2 skewers with the names of 2 villages in the sandbox, according to their relative locations on the map the *instructor* received in the assignment. The researcher explains that both *instructor* and *performer* have labels with the 4 cardinal directions added to the screen and sandbox. The *performer* does not have an assignment, so the *instructor* has to read or explain the assignment to him/her. The 15 minutes of the assignment are started now.

Orientation on other’s perspective:

Instructor orientates himself/herself on the *performer’s* perspective, by asking questions or giving instructions to visualize his/her position.

Ideal *instructor* behaviour:

Asks *performer:*

- Where is [cardinal direction] relative to your position?
- Where is [village name] in the sandbox?
- Is [village name] in [cardinal direction] to your left or right?
- Could you place an elevation in the sandbox in [relative location / cardinal direction]?

He/she then checks whether the answers to these questions comply with his/her expectations and/or adjusts these expectations.

Interpreting map and profiles:

Instructor interprets the maps and profiles, he/she received.

Ideal *instructor* behaviour:

- Checks orientation of map, relative to the sandbox.
- Checks which profile is in what position in the sandbox.
- Checks in what (cardinal) direction the profiles are drawn.

Creating 1st profile:

Instructor explains location and form of profile 1. *Performer* recreates this profile from instructions.

Ideal *instructor* behaviour:

- Mentions the location of the profile: "The profile runs all the way from the far western end of the landscape to the far eastern side, perpendicular to the length of the landscape/sandbox, starting at one fifth of the length, from the northern rim of the landscape."
- Waits for acknowledgments and/or answers control questions from the *performer.*
- Gives directions on the construction of the profile: "It starts in the west at a high level, so there should be a lot of sand there. Continue until it reaches orange / red / a warm colour. In the eastern direction, the height of the profile declines strongly. It should reach a low point at about a third of the entire profile. It should be blue / green / a cold colour at this point. From that low point, the slope increases gradually and reaches a similar height to the starting point in the easternmost point of the landscape."

Note that the examples use clear wording to support the instructions, such as using the cardinal directions instead of using for example 'upper left'.

Ideal *performer* behaviour:

- Checks locations. He/she can use visual cues such as placing some sand to mark a spot, or draw a line in the sand to mark a place.
- Constructs the profile according to directions.
- Asks many questions to check if the directions are followed correctly. For example to confirm whether or not the height or slope of a segment of the constructed environment is according to the profile.

Creating 2nd and 3rd profiles:

Comparable to creating the first profile. Strategies that seemed to work well in creating the 1st profile will be repeated. Strategies that were hindering communication or construction will be adjusted or discarded. This former experience accelerates the creation of the 2nd and 3rd profiles.

Refining profiles:

When there is time remaining on the 15 minute clock, the participants will try to refine the constructed profiles.

Ideal *instructor* behaviour:

- Attention to differences in height amongst profiles.
- Attention to curvature of the slopes.

Connecting profiles

Ideal behaviour of *instructor* and *performer*:

- Realizing that the landscape in between the profiles is not all the same.

- Constructing the remaining landscape in a logical way. Separate elevations should become connected, as well as lower points.

If this realization has not happened before 13 of the 15 minutes have lapsed, the researcher will ask:

“Have you thought about what the pieces of landscape in between the profiles should look like? There’s 2 minutes remaining.”

Evaluate:

The created landscape will be compared to the actual current elevation heat map of the landscape, of which the given profiles were derived. The students will be asked to point out corresponding and differing sections of the landscapes. The researcher then shows what differences and resemblances he notices. If the step of ‘connecting profiles’ has failed, he now shows how this could have been accomplished.

In-test

An in-test, similar to the pre-test, will be executed.

Swapping roles:

Instructor becomes *performer* and vice versa.

Repeating steps 2 through 8:

In accordance with their new roles, the participants begin the second assignment. The *instructor* receives new profiles and a new map of a different region. The participants can apply their newly gained insights in the assignment on this second trial.

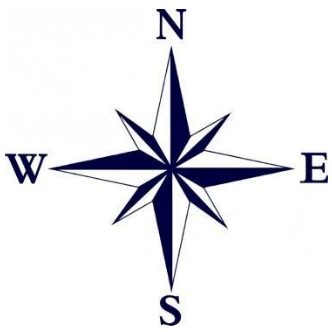
Post-test:

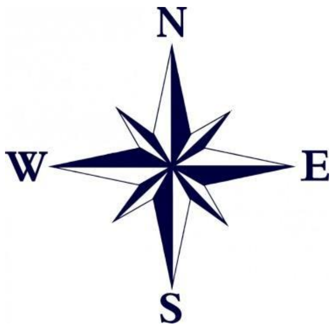
A post-test, similar to the pre-test, will be executed.

Appendix B: Assignment materials

Landschap namaken:

Jullie gaan samen proberen het landschap rondom Deventer na te maken (zie de kaart hieronder). Alleen jij ziet de kaarten, terwijl je klasgenoot alleen maar het zand mag verplaatsen. Jullie zijn gescheiden door een doek, dus je zult duidelijk moeten communiceren!
Jij krijgt 3 hoogtelijnen te zien met de daarbij behorende hoogteprofielen. Aan de hand van die 3 profielen probeer je zo goed mogelijk het originele landschap af te leiden. Je moet dus ook bedenken hoe het landschap tussen de hoogtelijnen er uit zou kunnen zien.
Jij vertelt je klasgenoot wat hij moet doen met het zand. Op het computerscherm zie je wat er verandert in de zandbak doordat je klasgenoot het zand verplaatst.
Jullie krijgen 15 minuten de tijd om het landschap zo goed mogelijk na te maken. Elke 5 minuten zal de onderzoeker vertellen hoeveel tijd je nog hebt. Als je eerder klaar bent, zeg je dat duidelijk.
Zet hem op!

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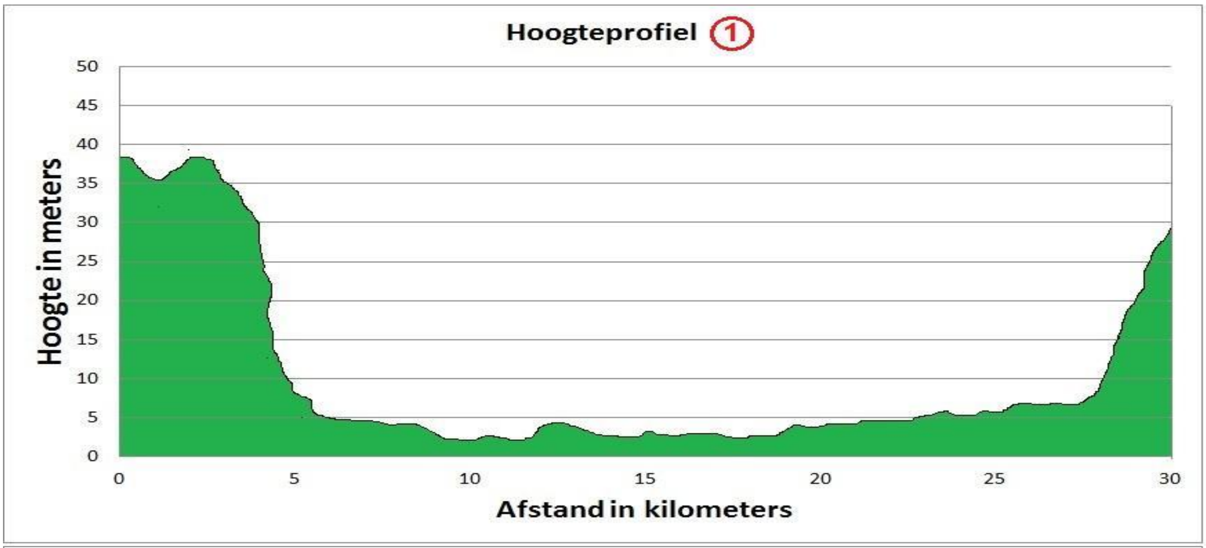
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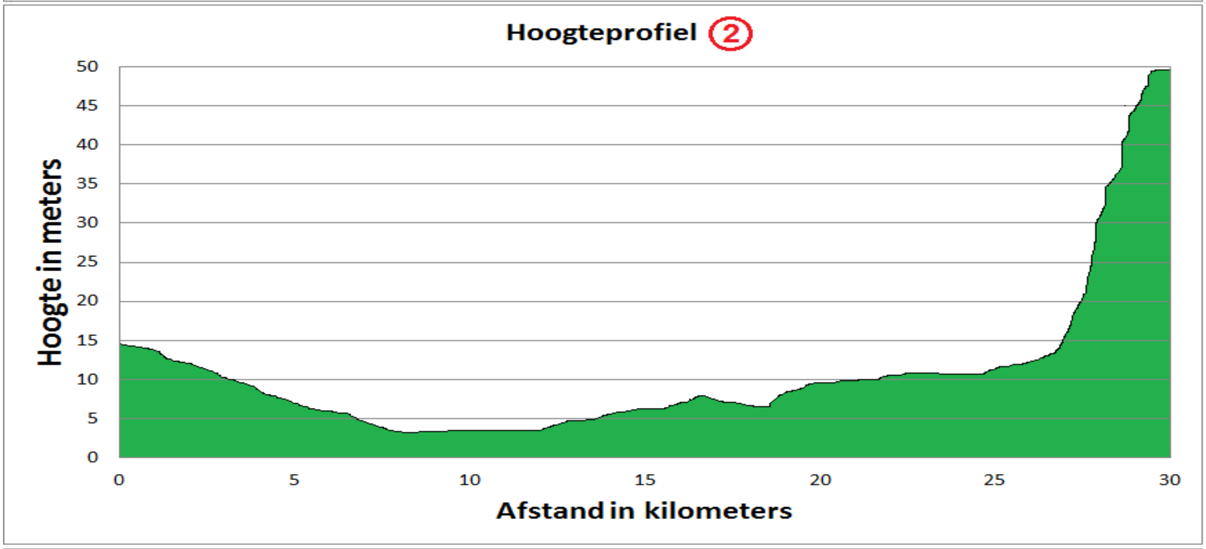
Afstand in kilometers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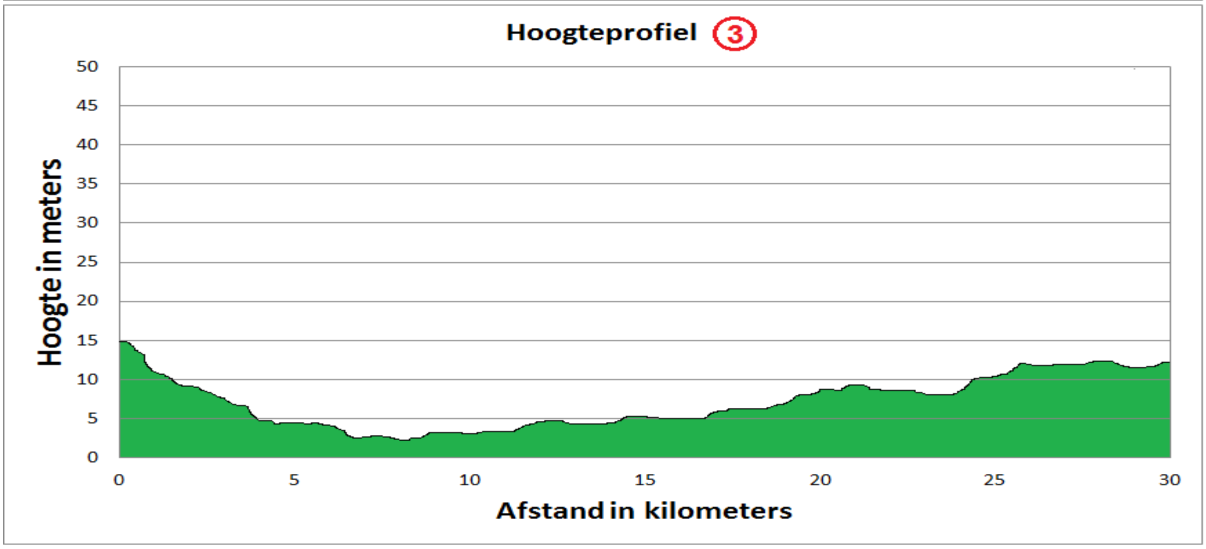
Hoogteprofiel 3
Hoogte in meters
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Afstand in kilometers

Landschap namaken:

Jullie gaan samen proberen het landschap rondom Deventer na te maken (zie de kaart hieronder). Alleen jij ziet de kaarten, terwijl je klasgenoot alleen maar het zand mag verplaatsen. Jullie zijn gescheiden door een doek, dus je zult duidelijk moeten communiceren!
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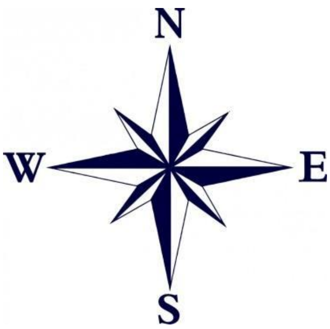
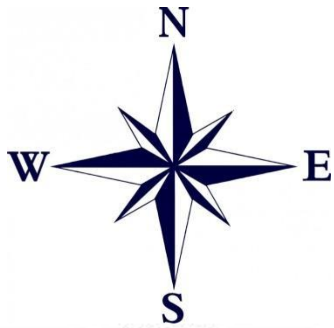
Zet hem op!

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Amersfoort
Hoevelaken
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Barneveld
Leusden
Soesterberg
A28
Zeist
Woudenberg
Scherpenzeel
Lunteren
A30
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Odijk
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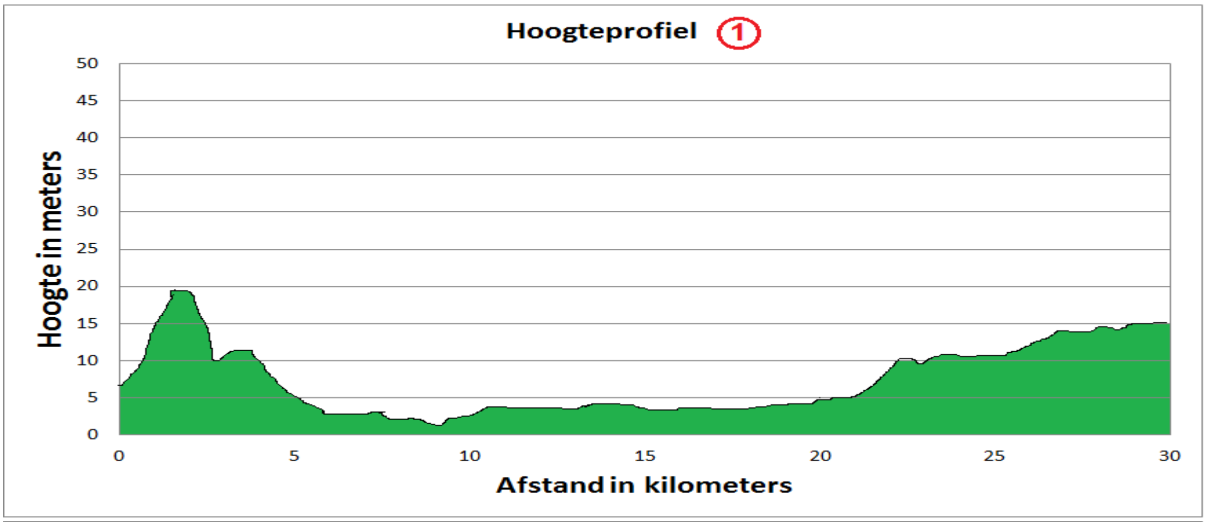
Doorn
Veenendaal
Leersum
Amerongen
Wijk bij Duurstede
Rhenen
Opheusden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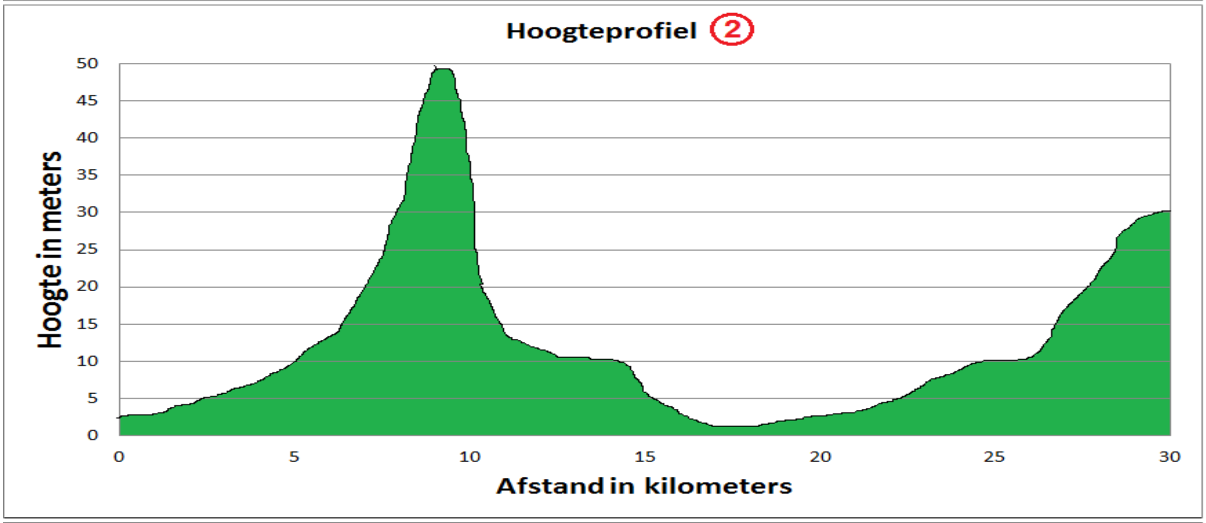
Afstand in kilometers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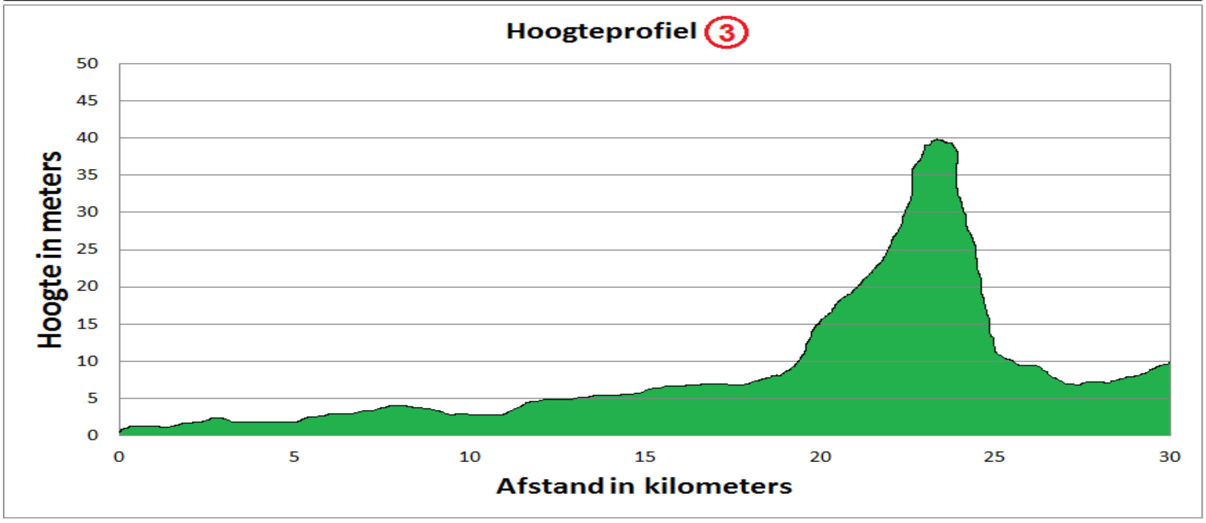
Hoogteprofiel 3
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Hoogte in meters
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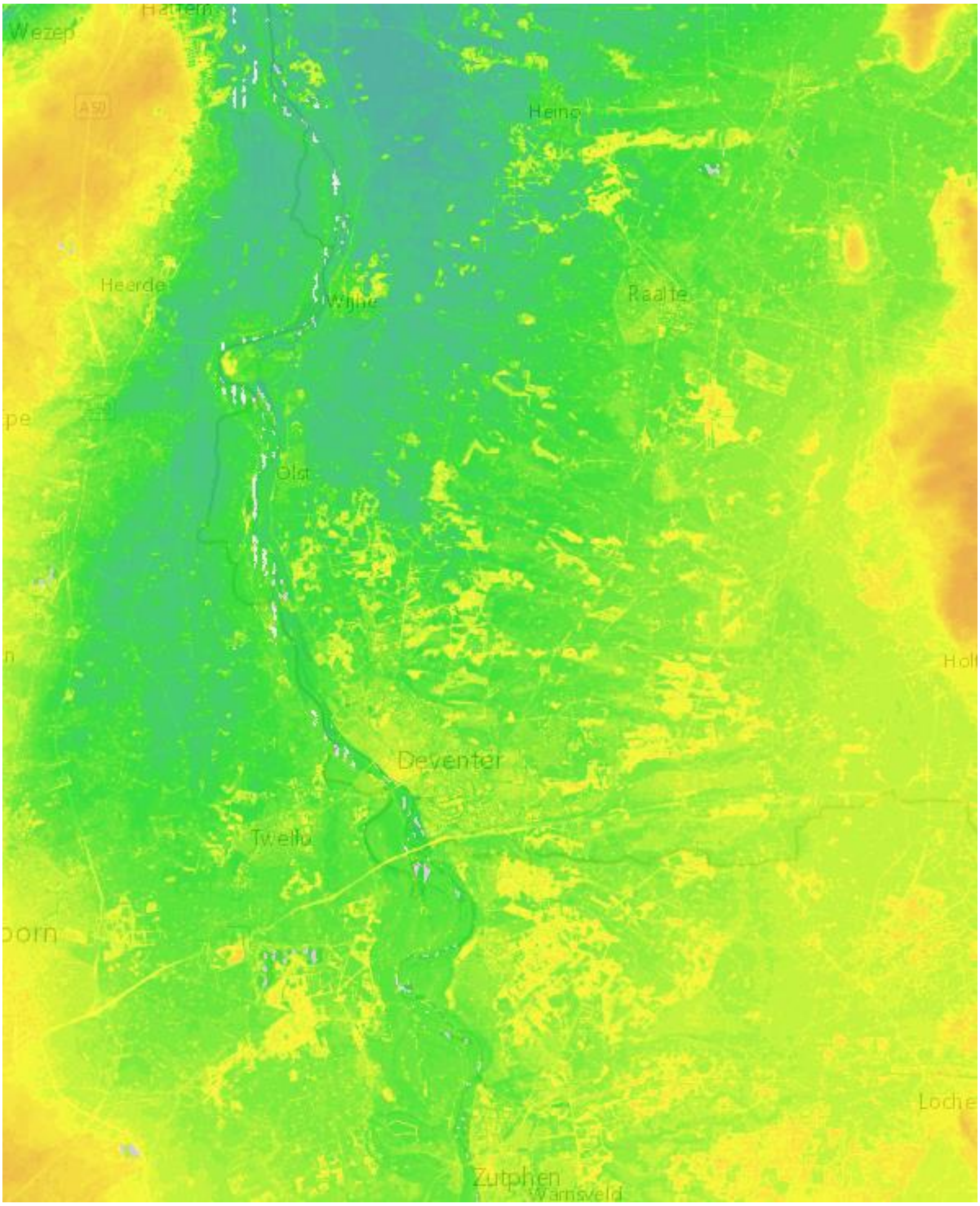
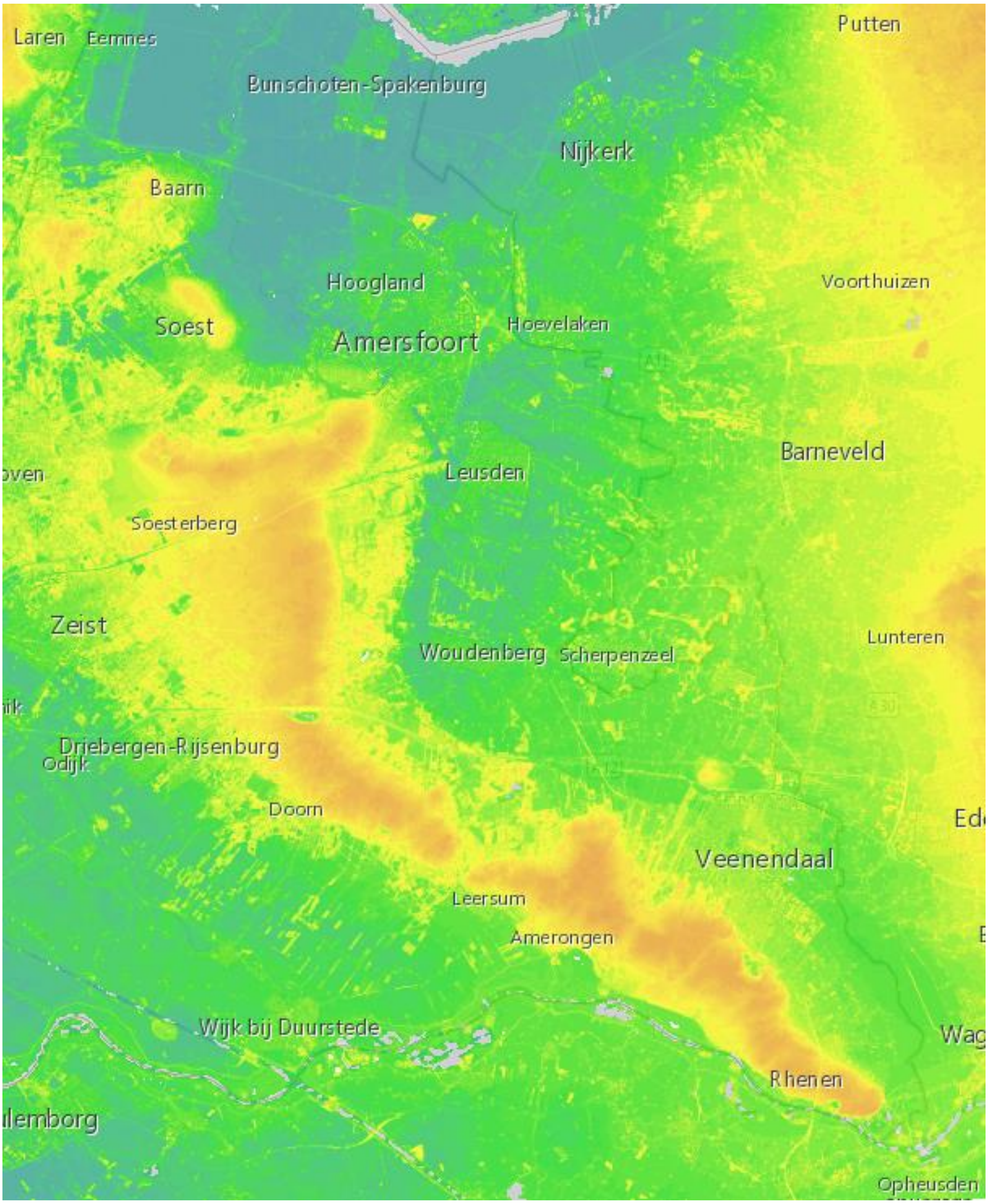
Afstand in kilometers

Resultaat voor reflectie op proces Wezep-Zutphen:

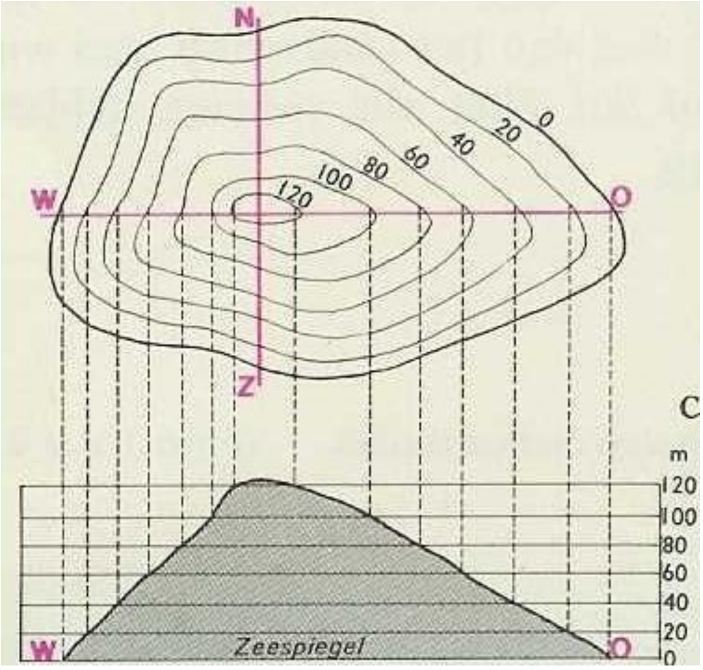


Resultaat voor reflectie op proces Laren-Opheusden:



Appendix C:
Pre-, in- and post-test; explanation, maps and profiles.

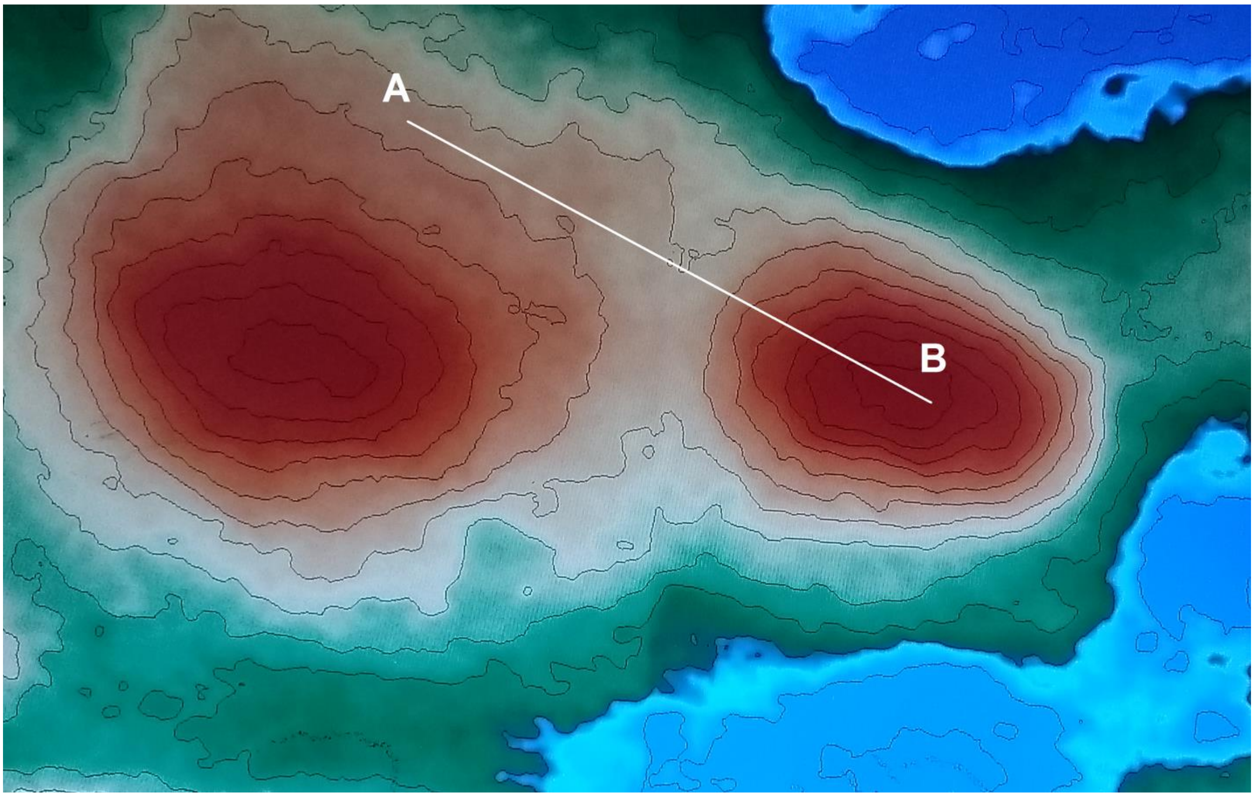
Hoogtekaarten



Om op een tweedimensionale kaart de hoogtes van bergen en de dieptes van dalen weer te geven, gebruiken we topografische kaarten. In topografische kaarten wordt dit gedaan met behulp van hoogtelijnen. Voor deze hoogtekaarten met hoogtelijnen zijn een aantal regels vastgesteld:
Ten eerste stelt elke afzonderlijke hoogtelijn in een kaart een vaste bepaalde hoogte voor. Als je in een omgeving een route zou volgen, die op de kaart precies over een hoogtelijn loopt, zou je dus gedurende je wandeling niet omhoog of omlaag gaan.
Ten tweede is het verschil in hoogte tussen twee hoogtelijnen altijd gelijk. Als je van de ene hoogtelijn naar de andere hoogtelijn in een kaart loopt, loop je dus altijd omhoog of omlaag.
Verder worden in sommige kaarten getallen toegevoegd aan sommige lijnen. Dit maakt het mogelijk om te bepalen welke van de hoogtelijnen hoger en welke lager ligt. Een andere manier om dit duidelijk te maken is met behulp van kleur. Over het algemeen geldt dan dat warmere kleuren (roodtinten) hoger gelegen zijn, dan koude kleuren (blauwtinten).
In de figuur hiernaast zie je hoe van een hoogteprofiel (onderste afbeelding) een hoogtekaart (bovenste afbeelding) kan worden gemaakt.

Je krijgt nu een aantal hoogtekaarten aangereikt met een lijn tussen de punten A en B. Daarnaast krijg je de bijbehorende hoogteprofielen, in een willekeurige volgorde. Leg de profielen op de kaarten waarvan je denkt dat ze bij elkaar horen. Je krijgt hiervoor twee minuten de tijd.

Let op: Bij deze kaarten zijn witte delen het hoogst, gevolgd door rood, dan geel, dan groen en uiteindelijk blauw als laagste punt.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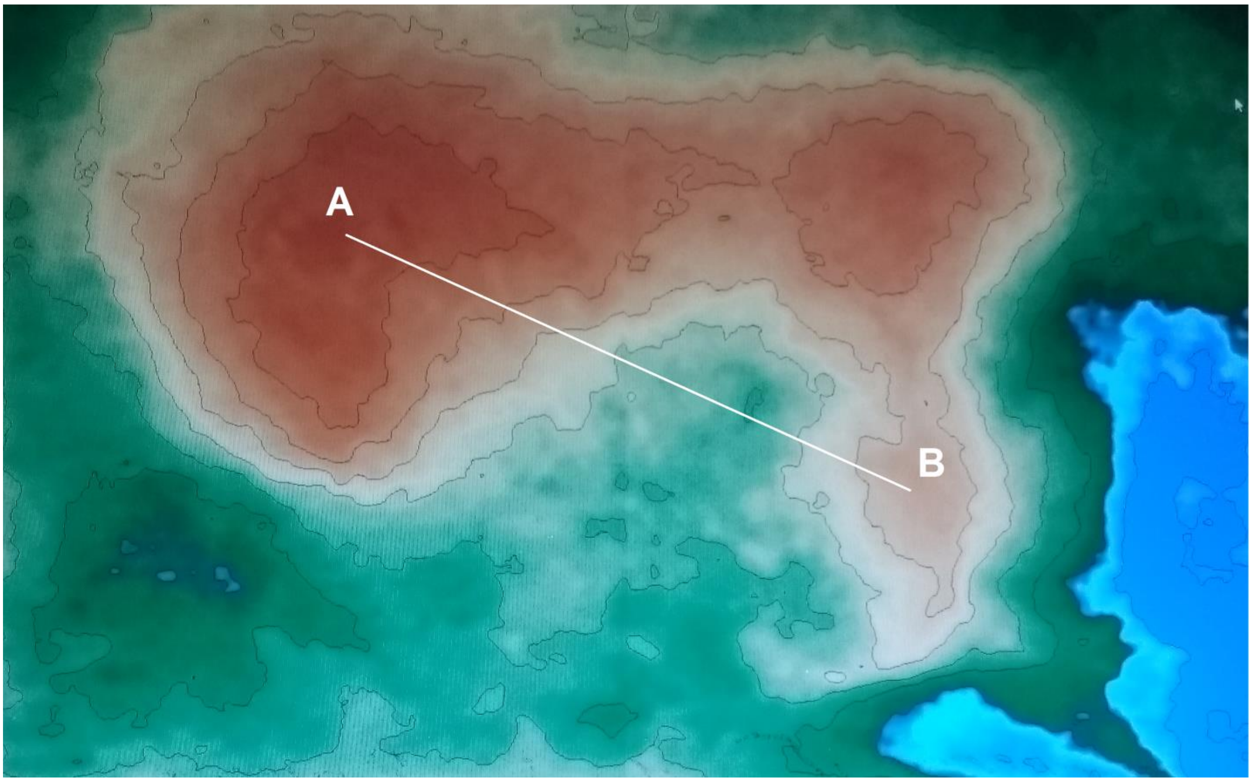
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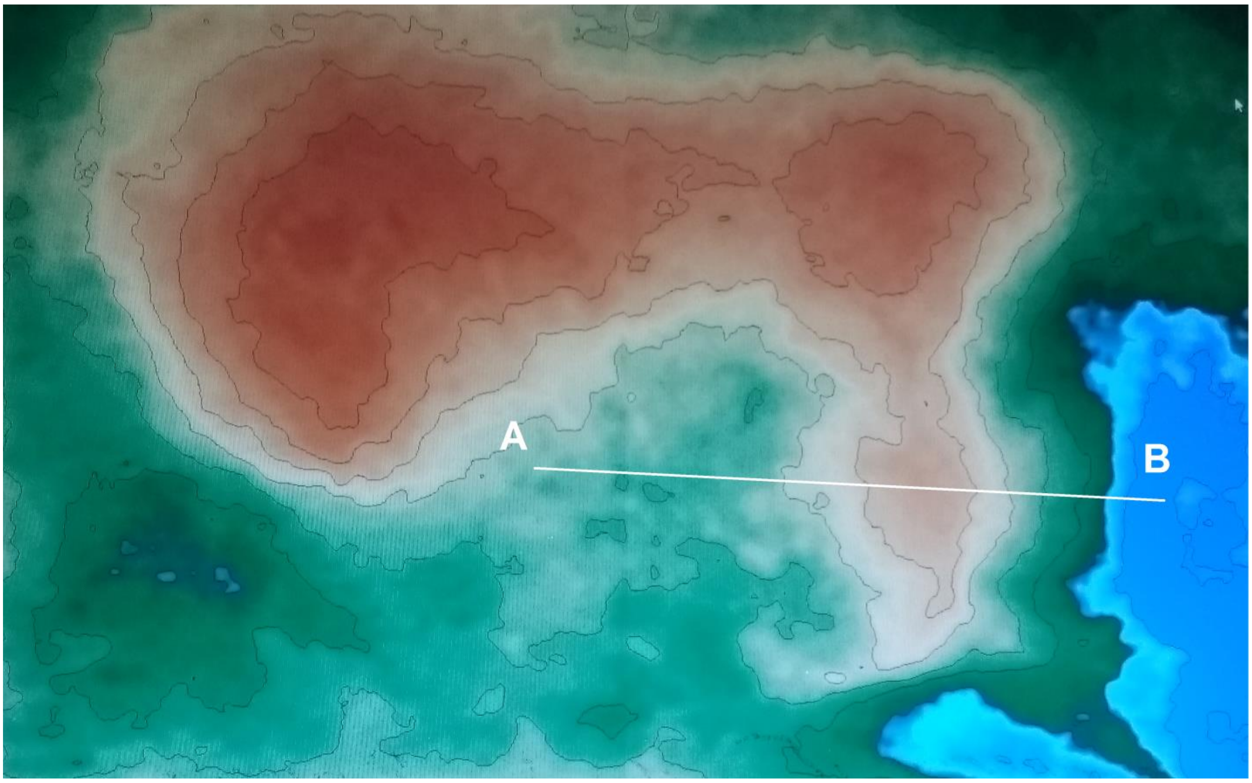
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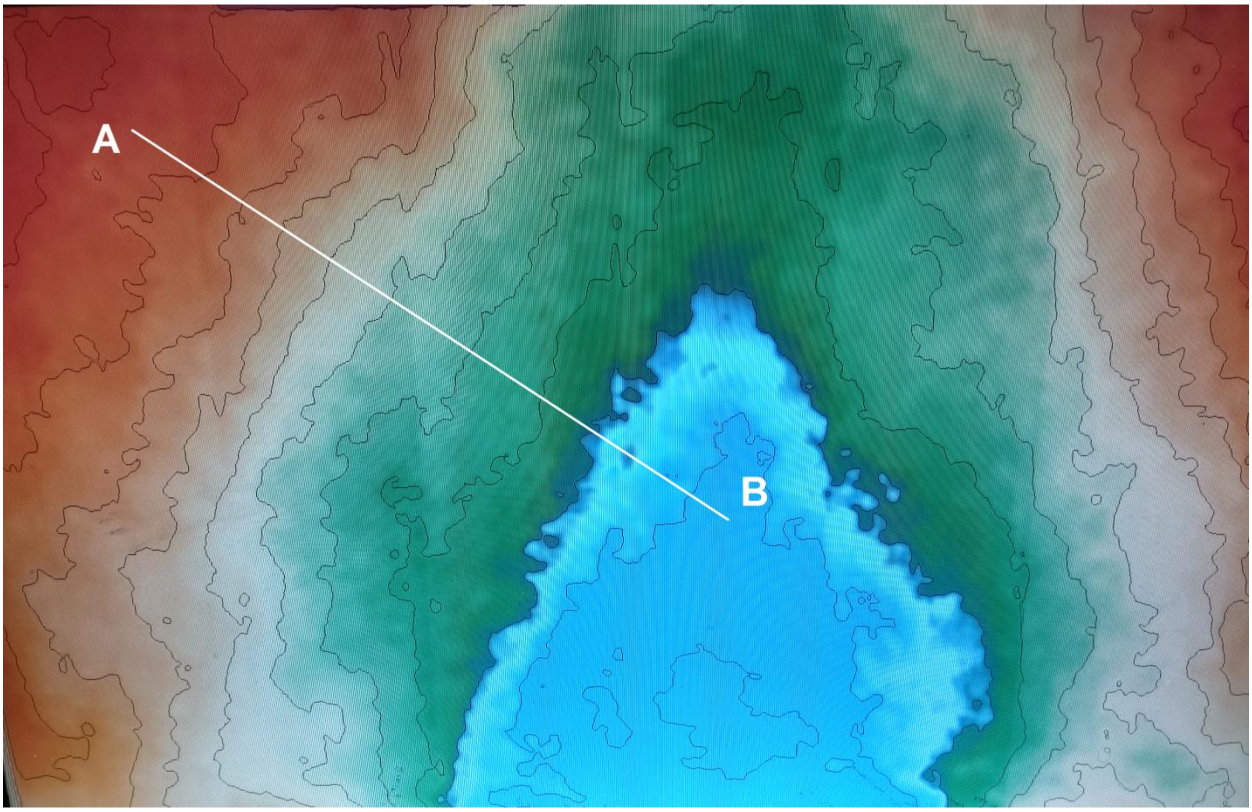
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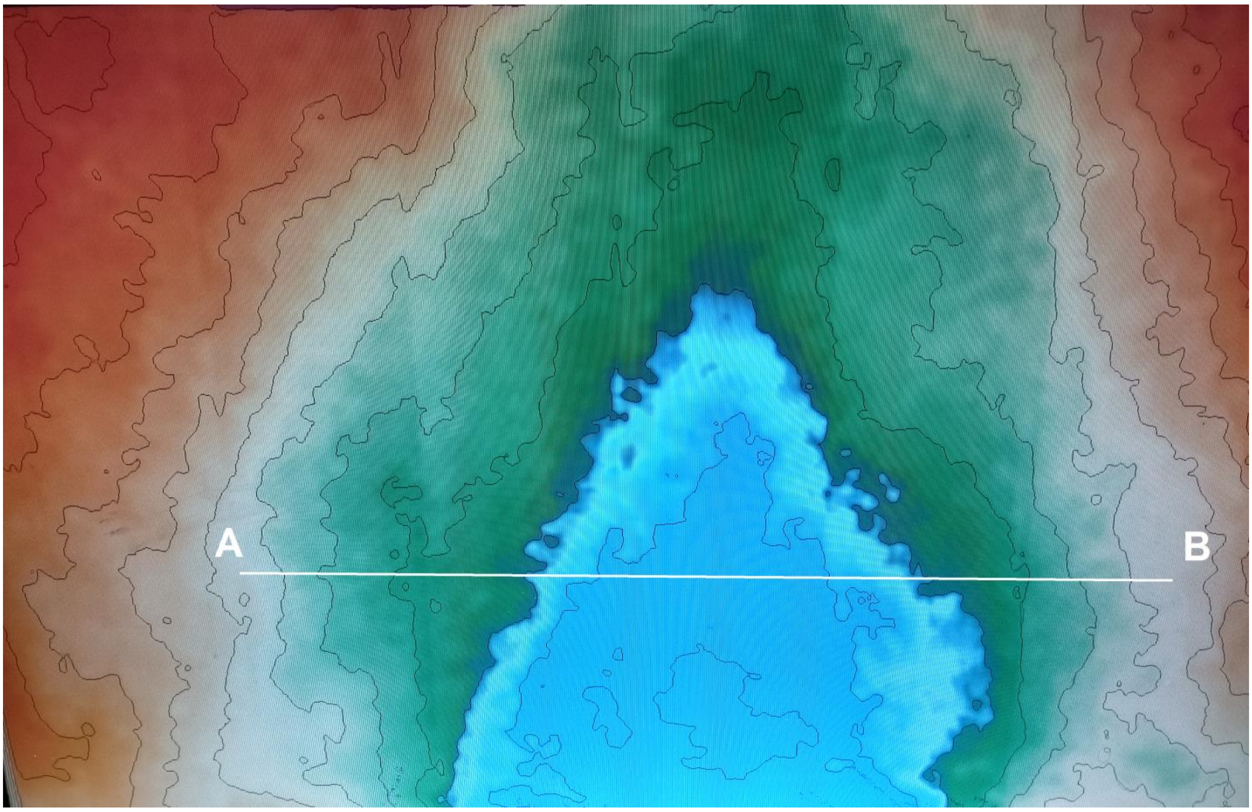
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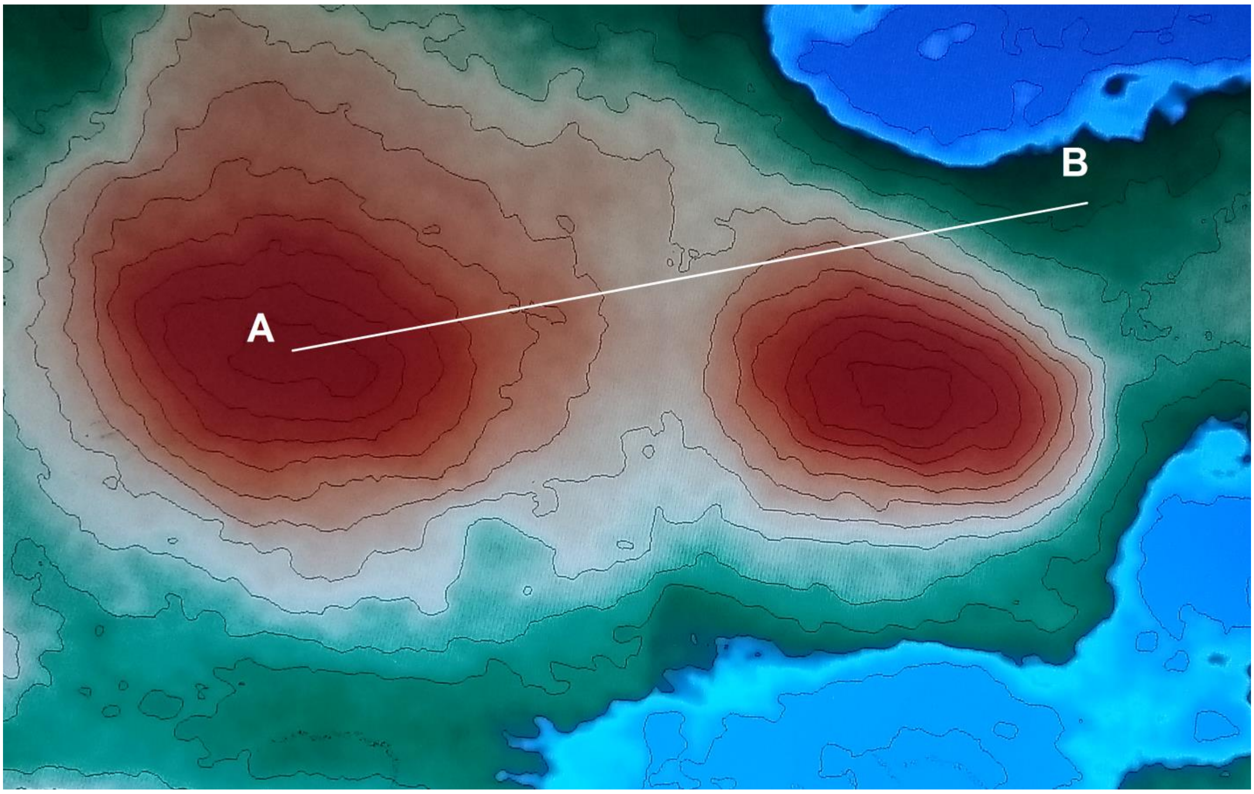
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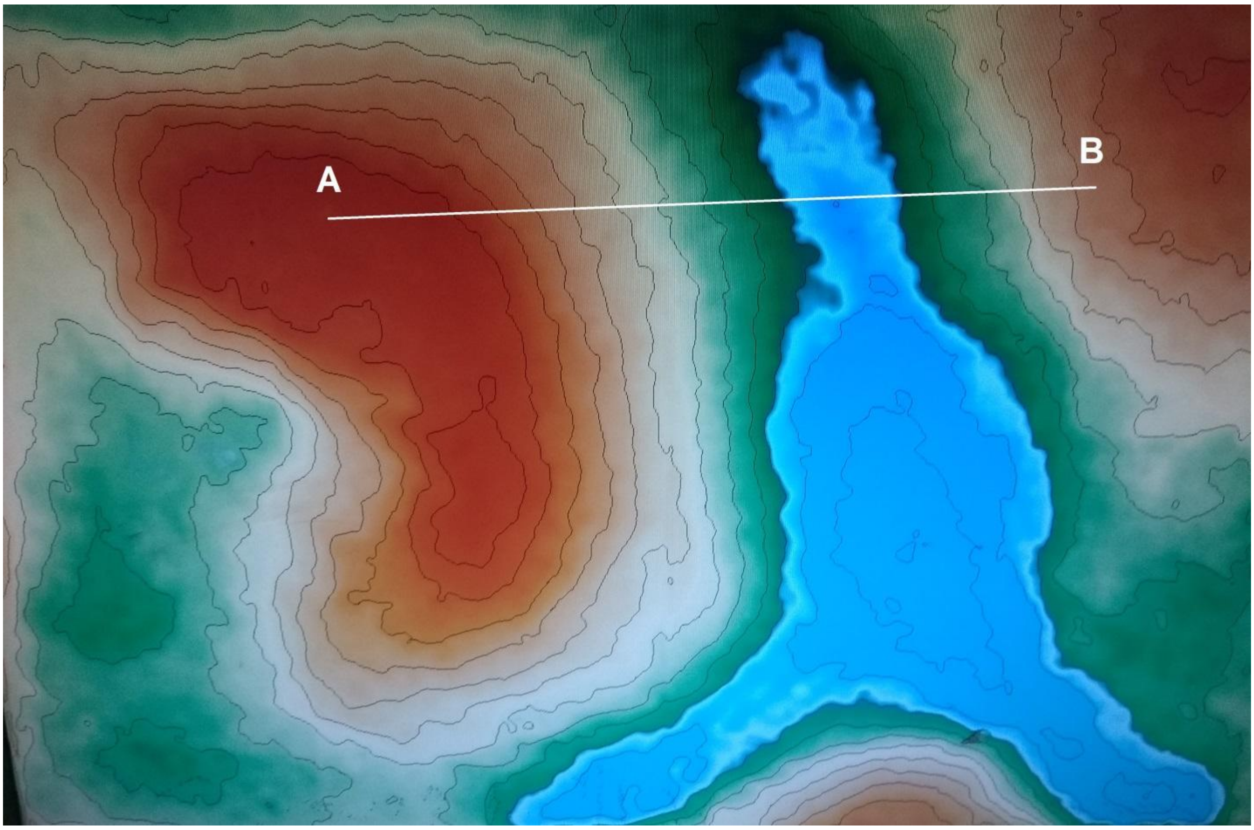
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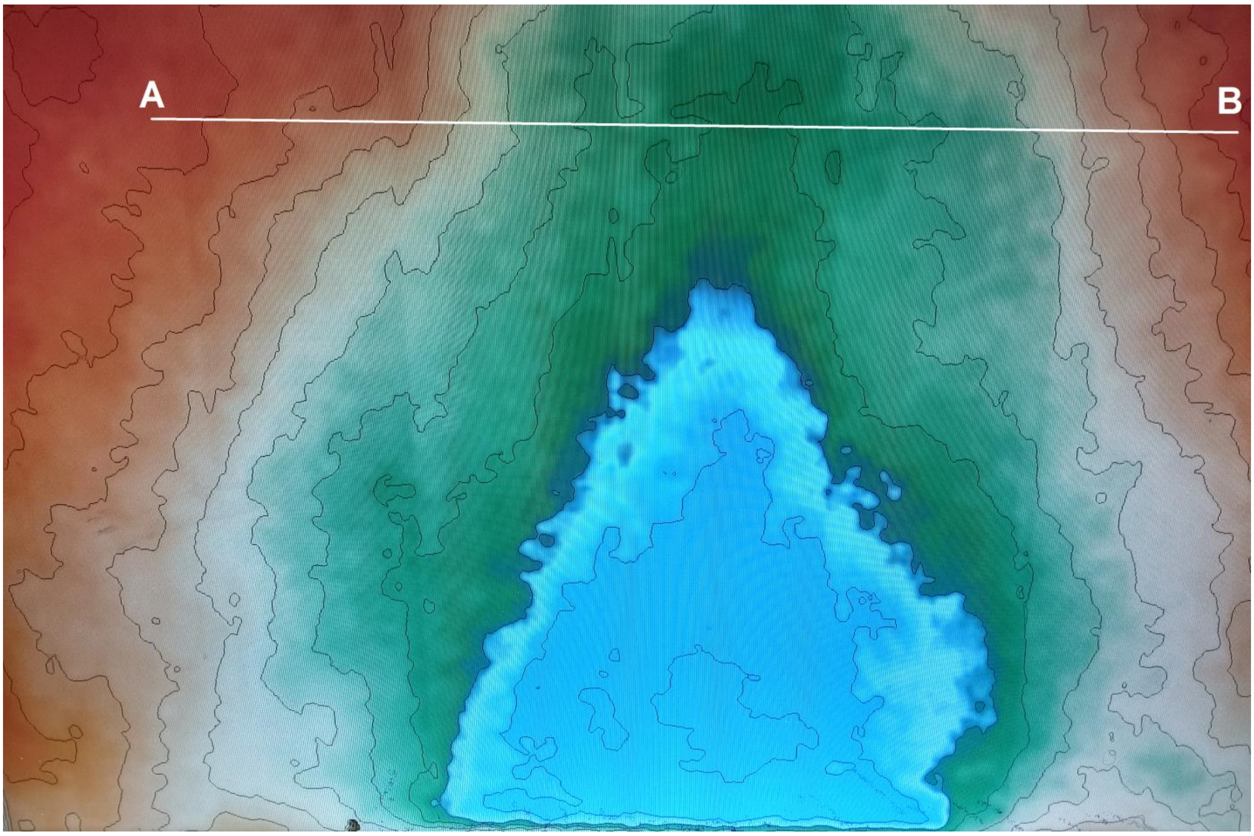
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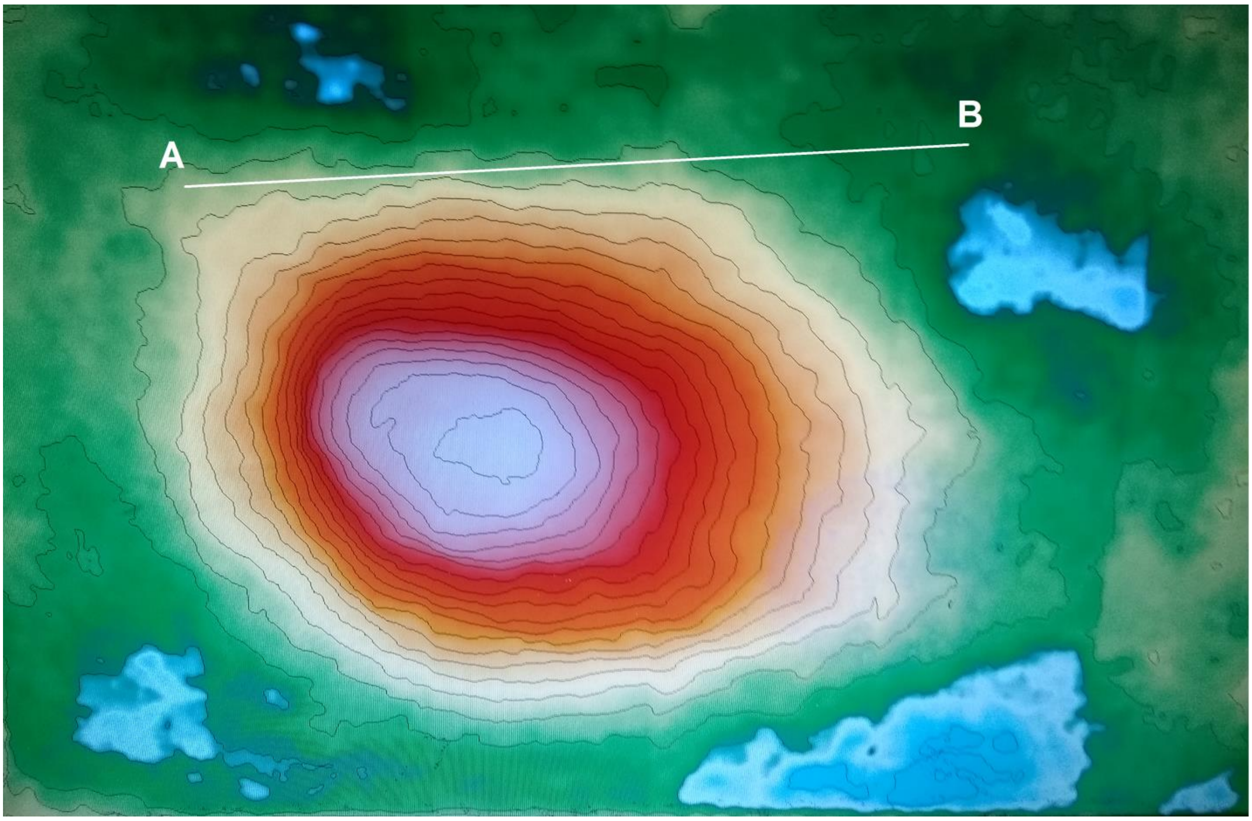
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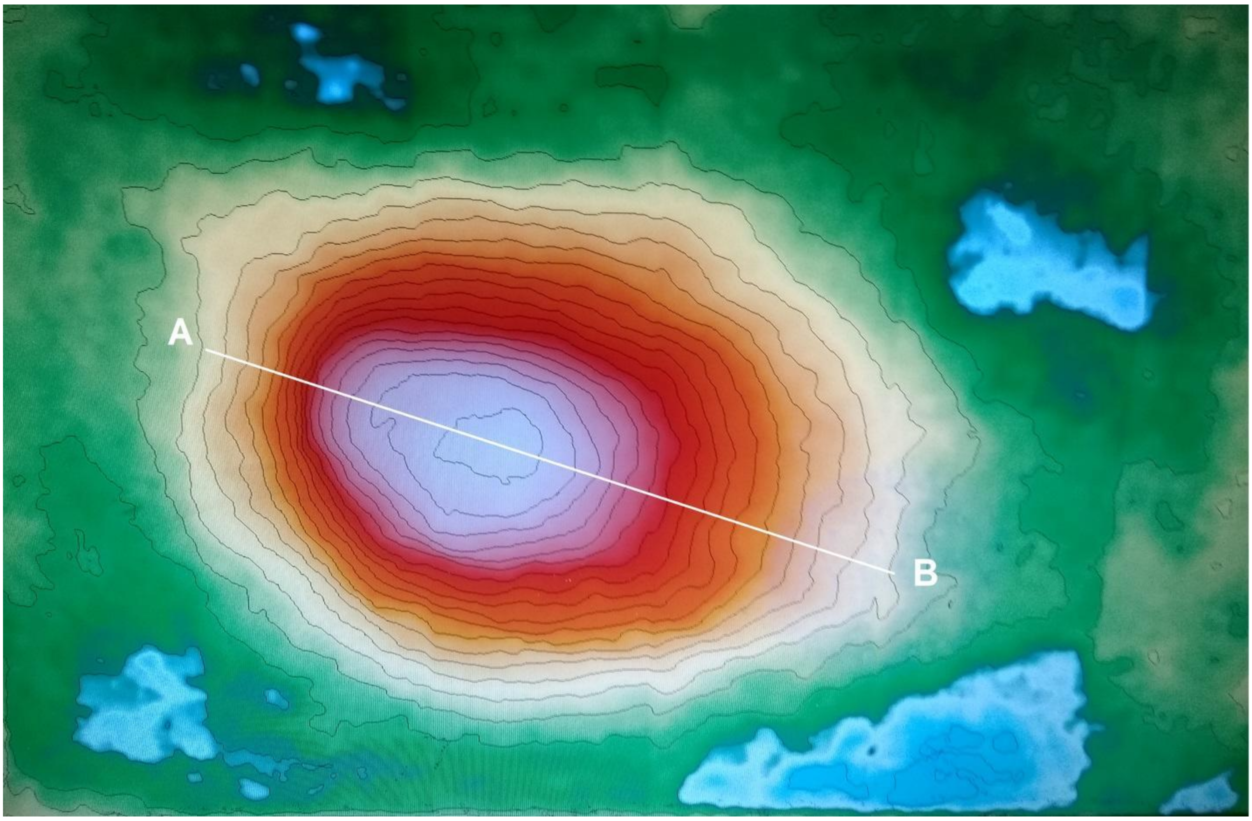
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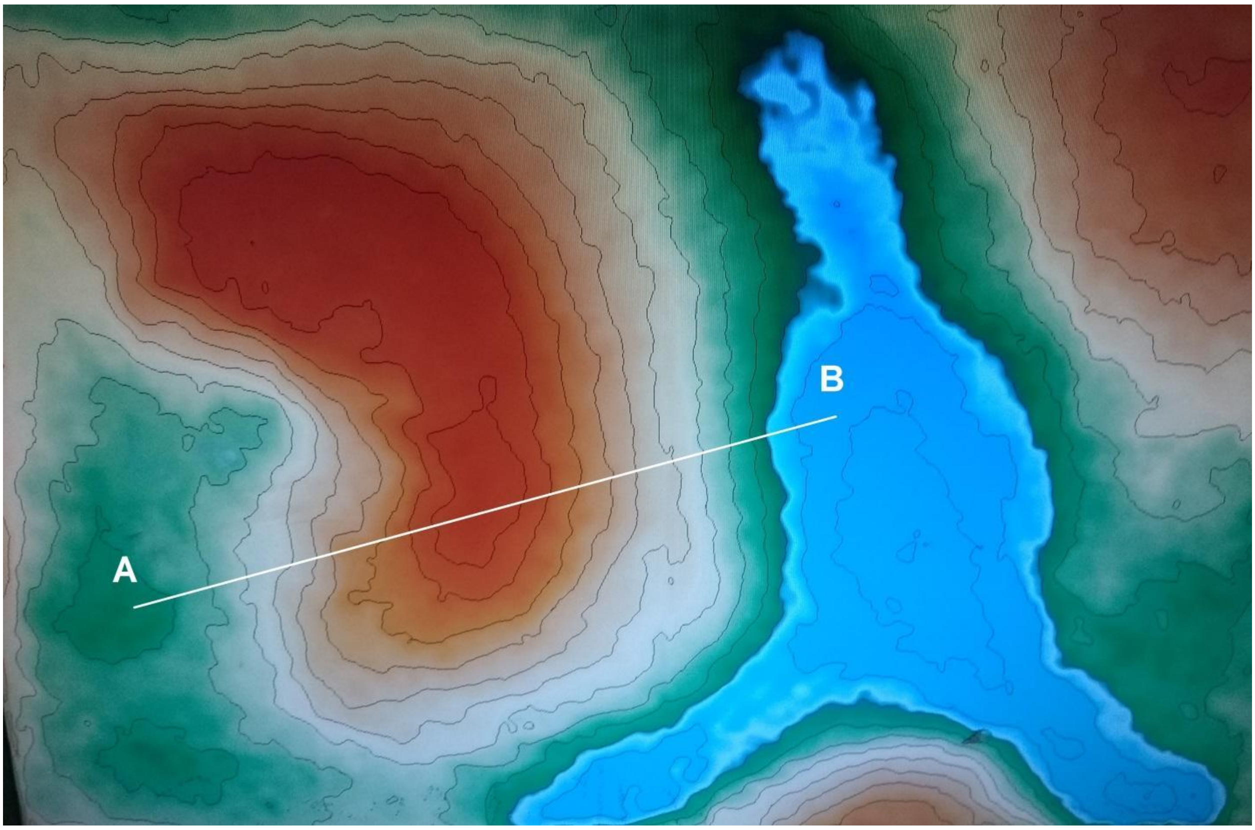

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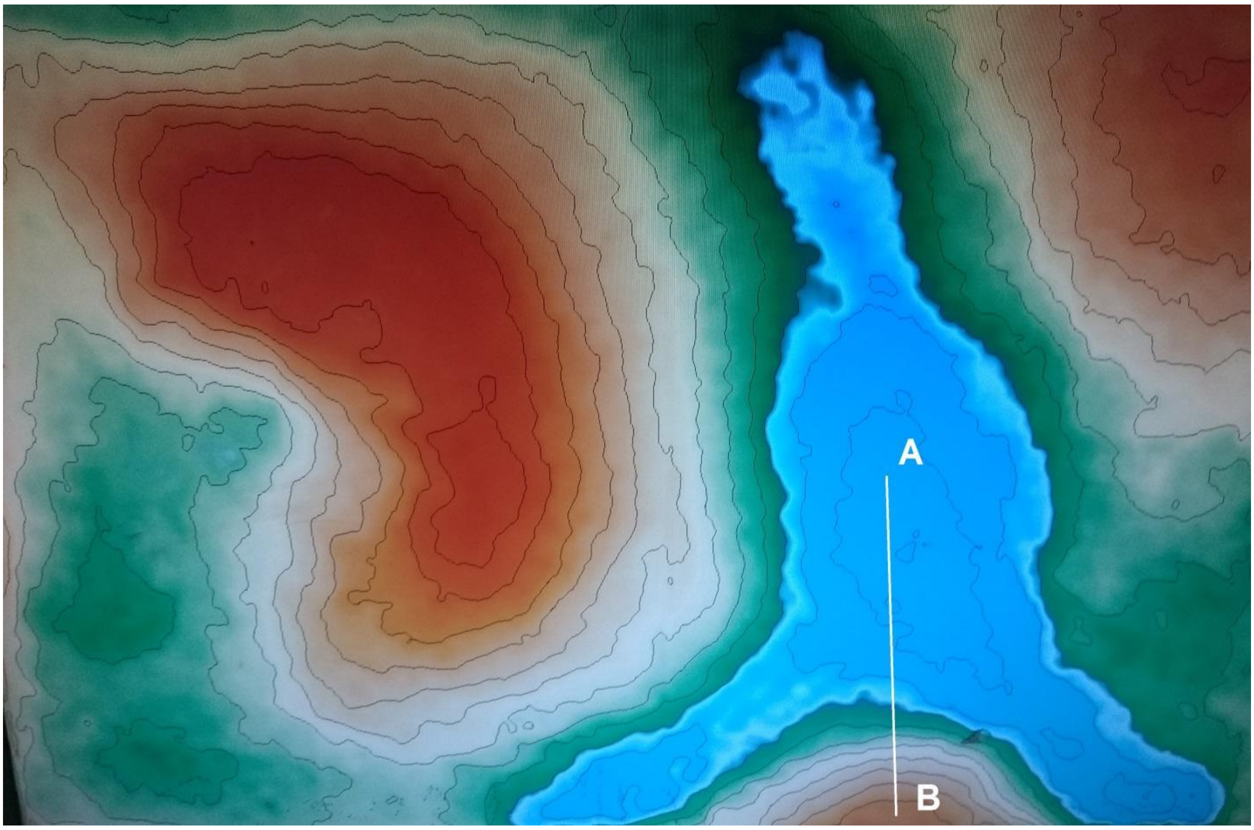

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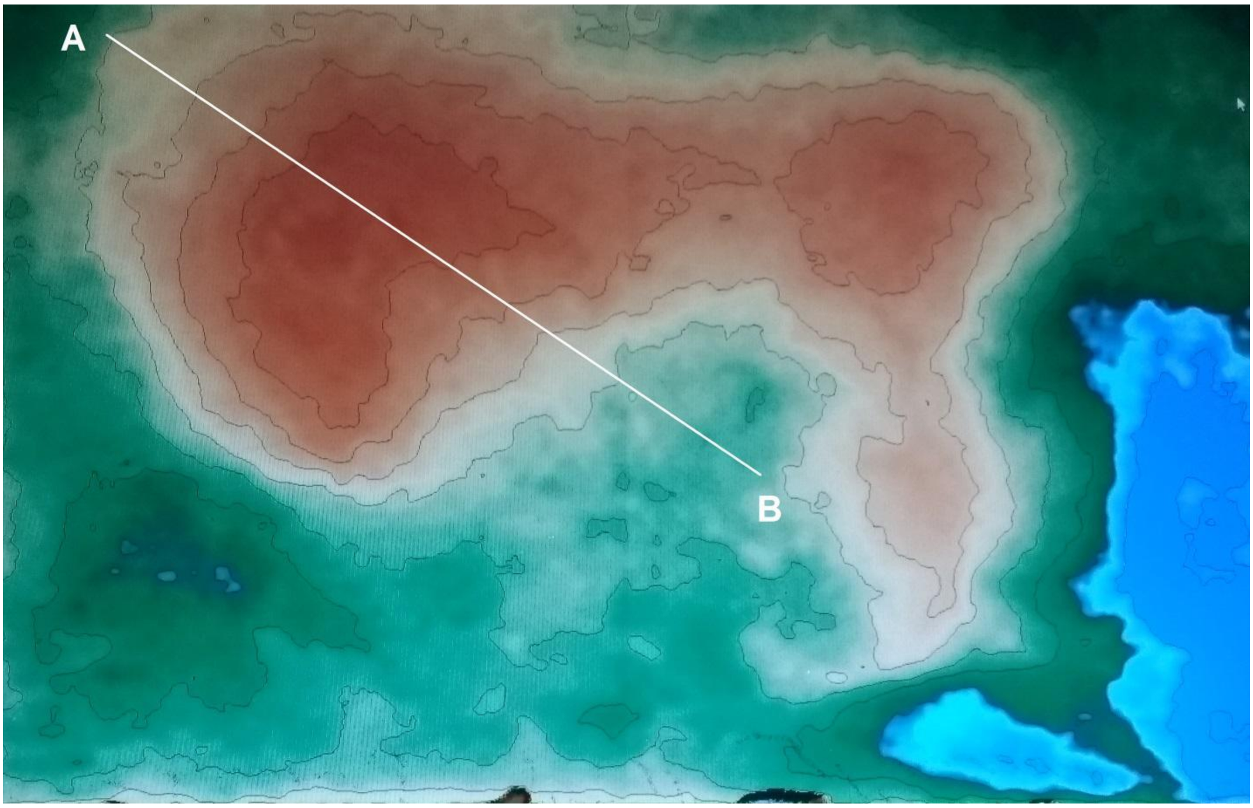
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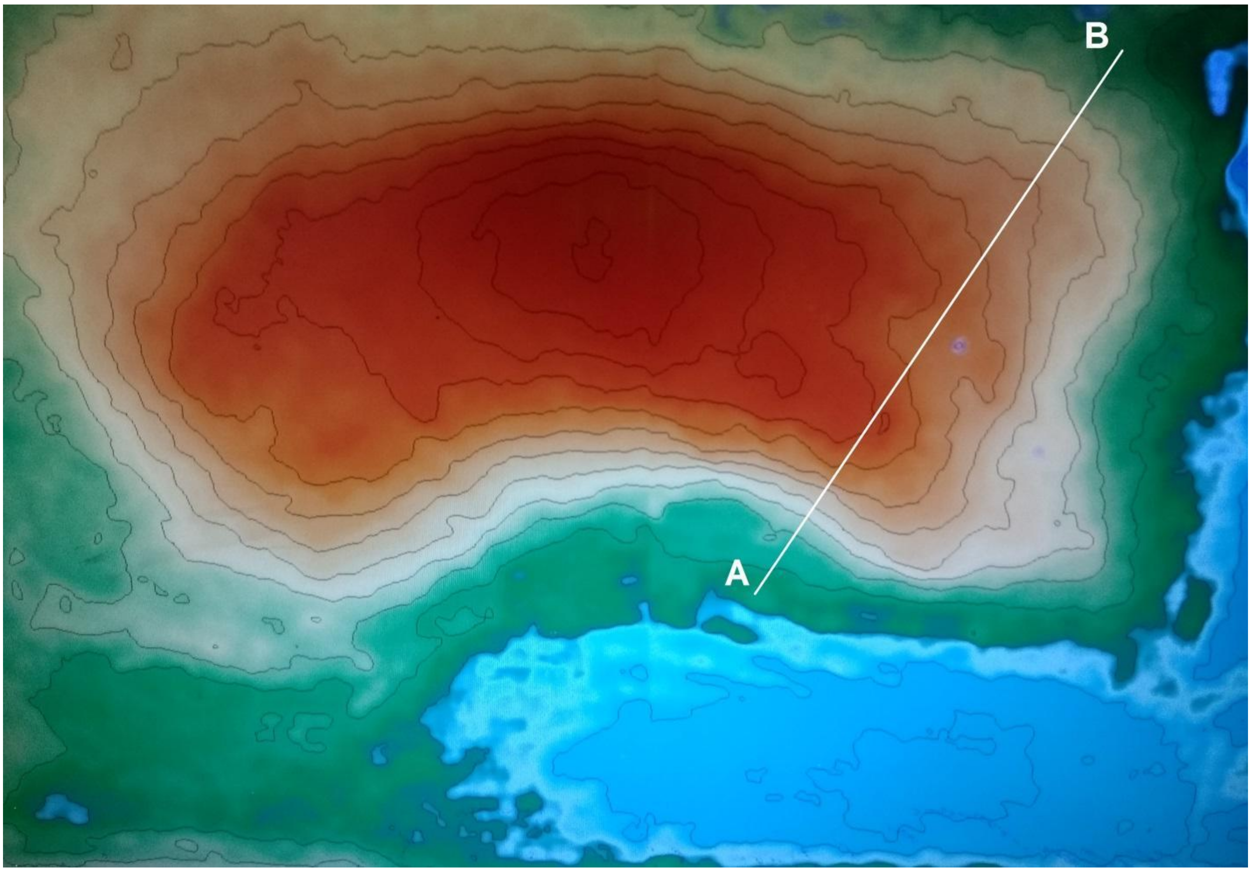
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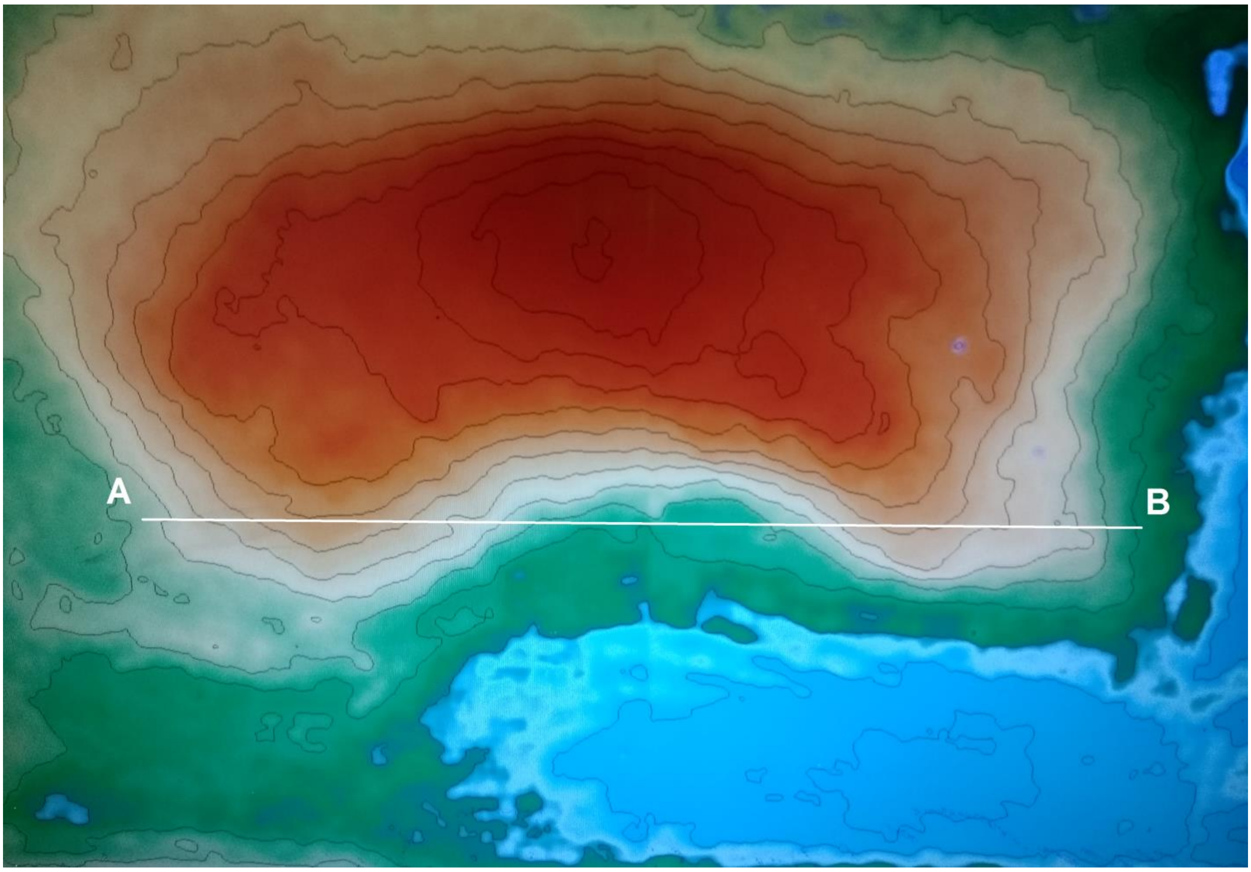
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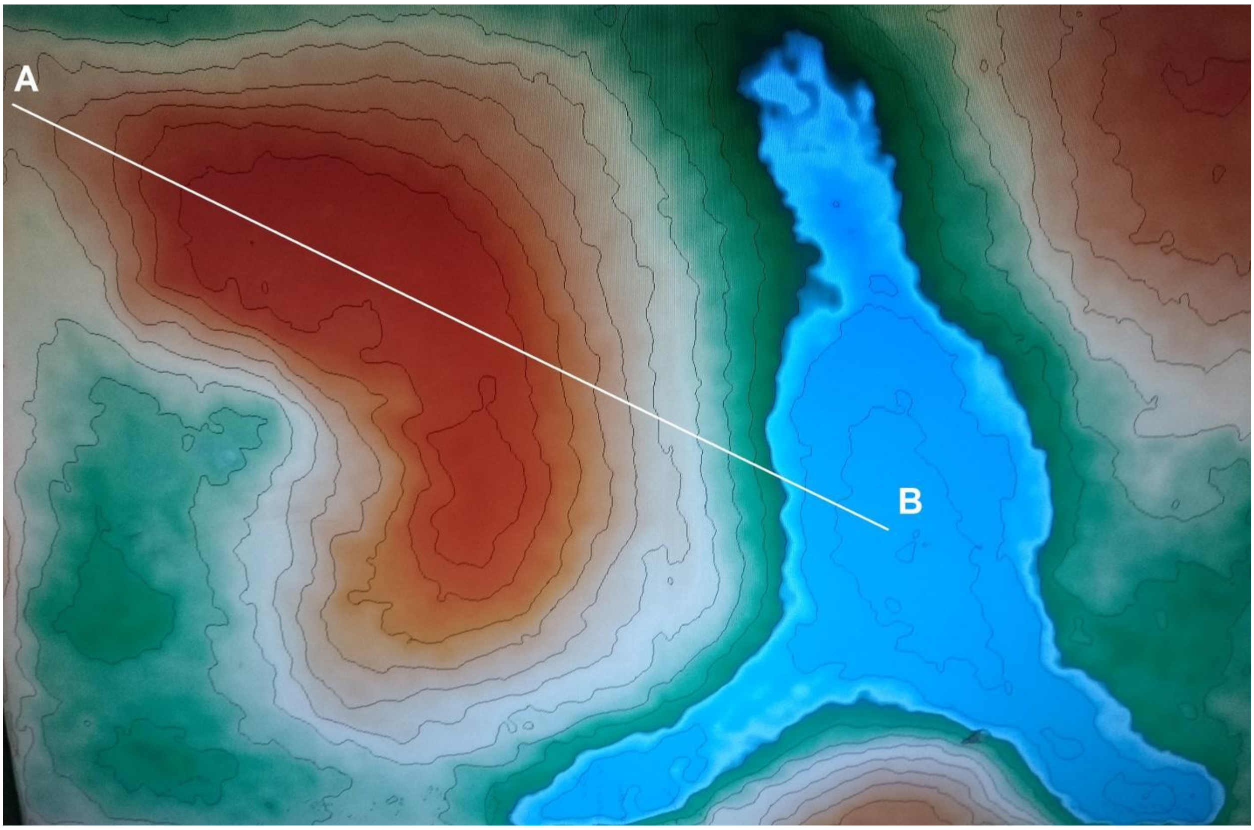
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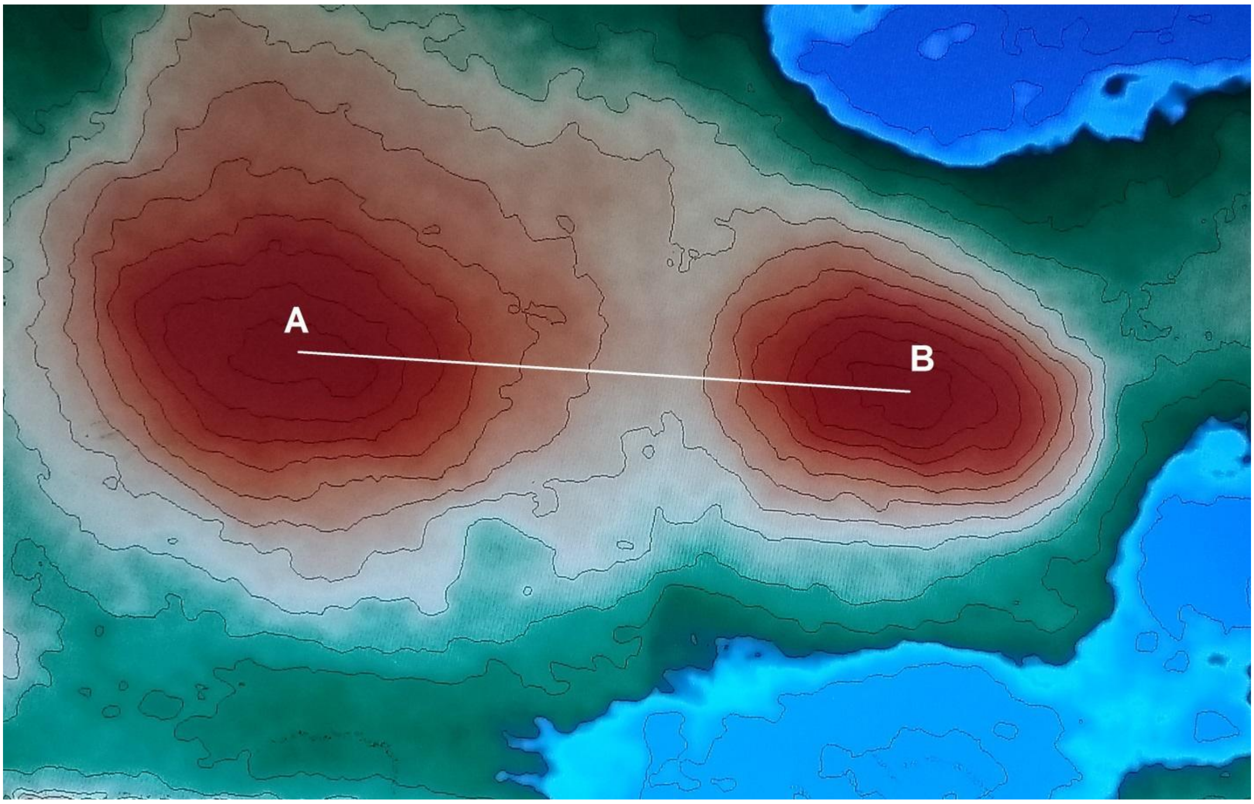
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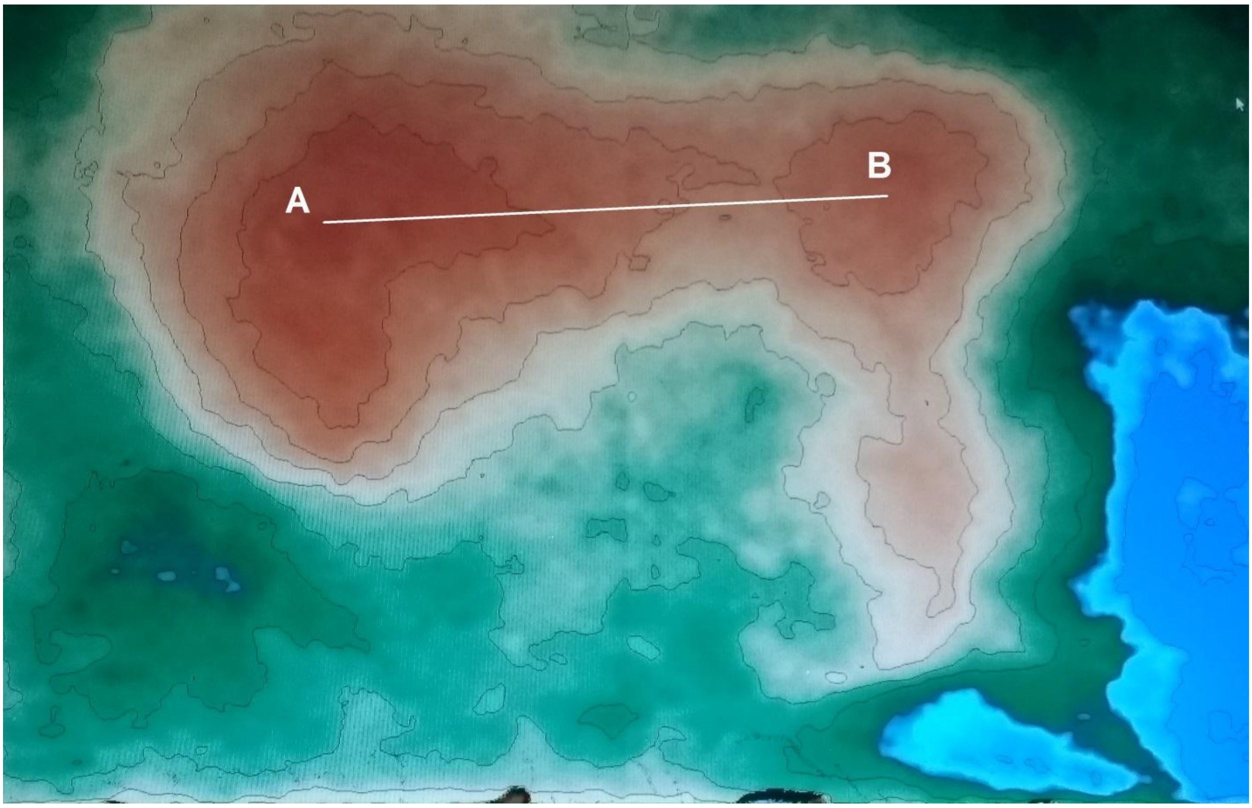
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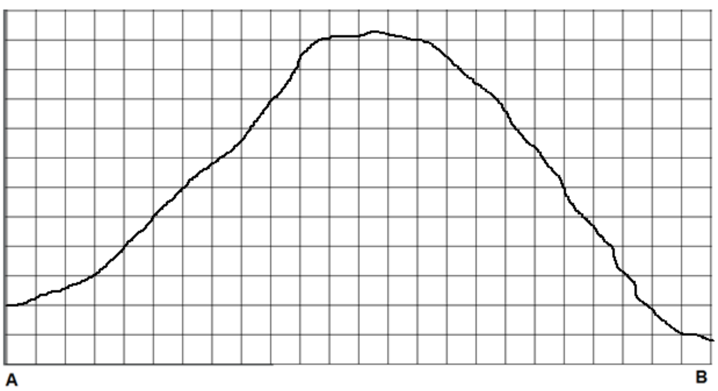
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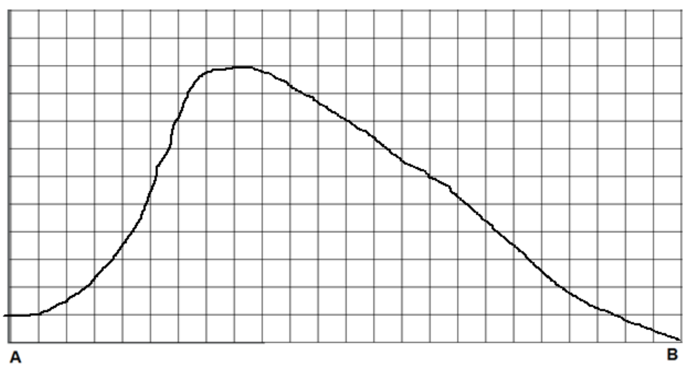
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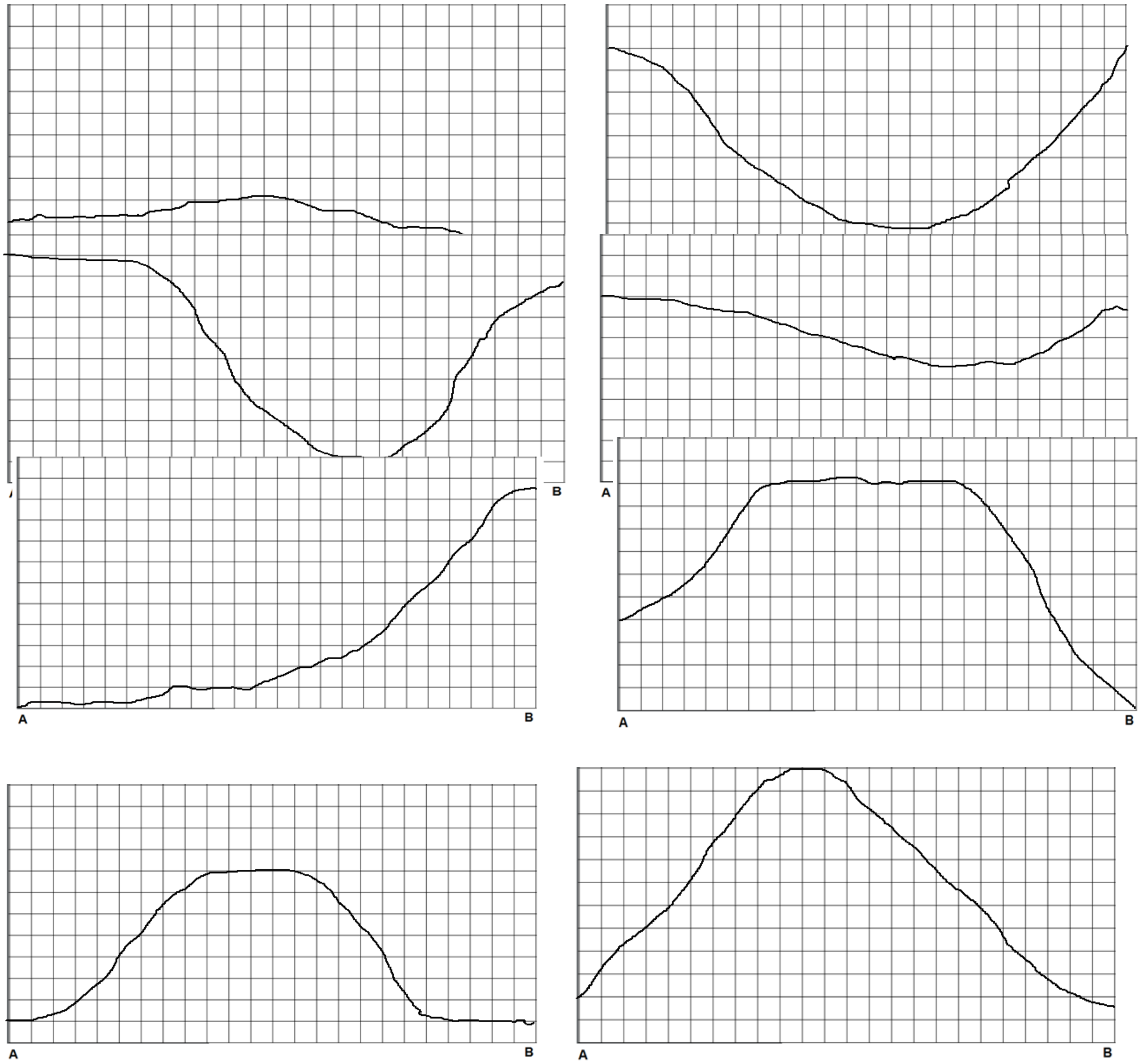
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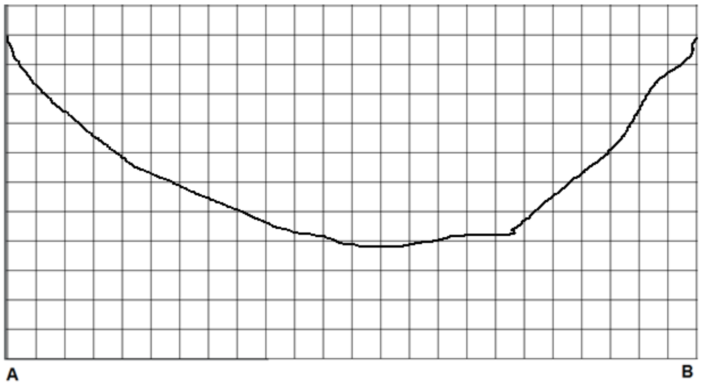
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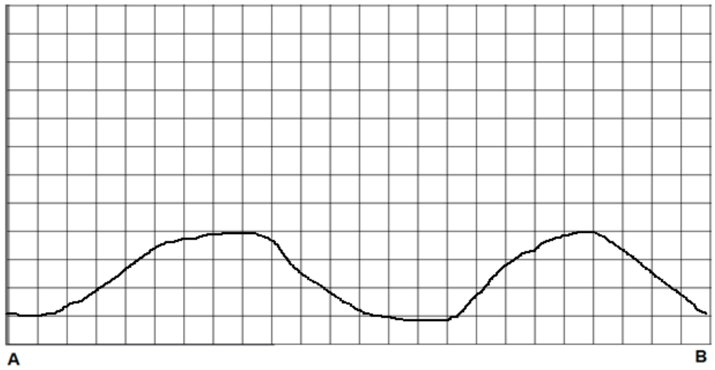
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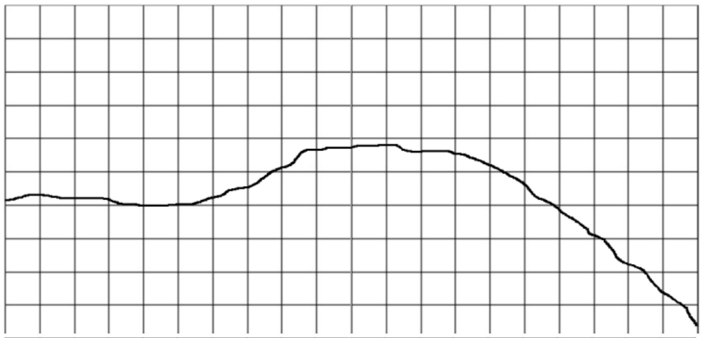

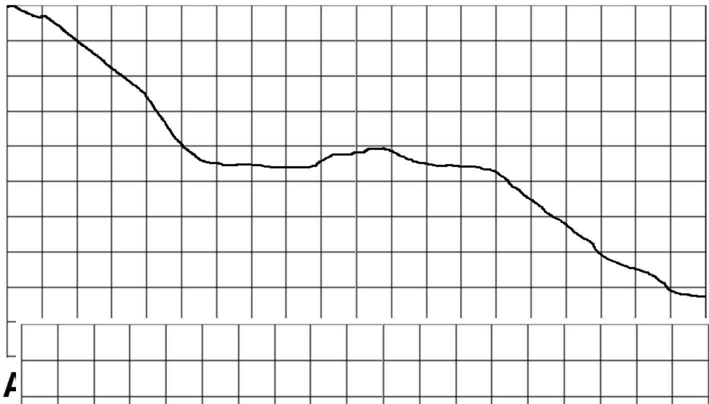
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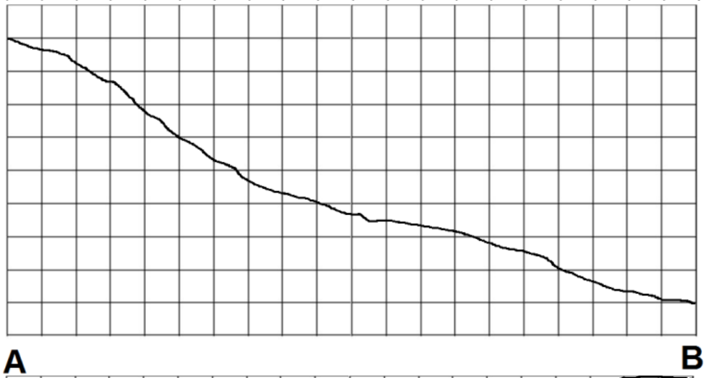
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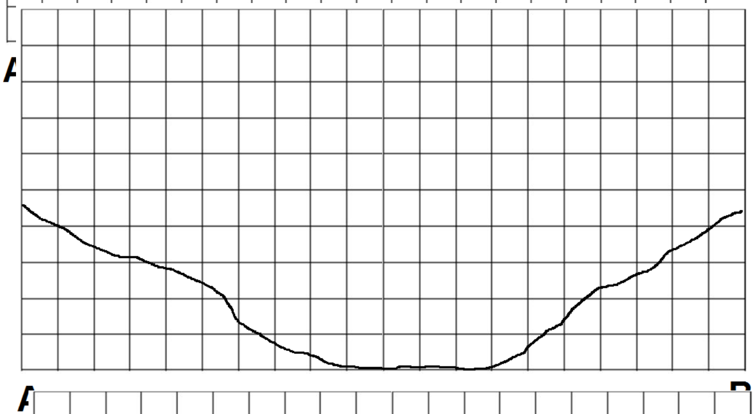
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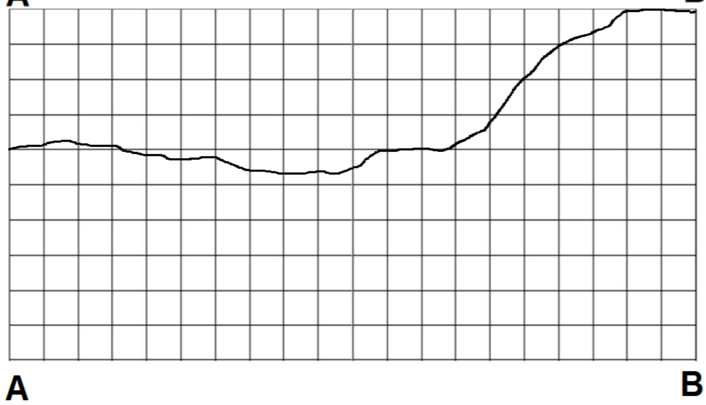
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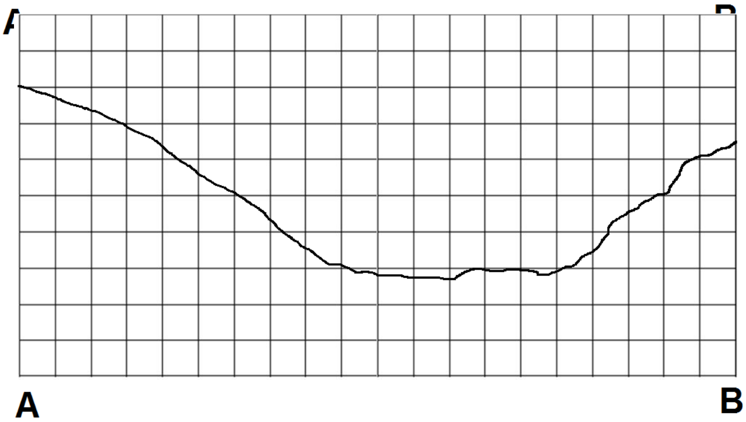
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