The Impacts of Using Augmented-Reality Sandbox on Students' Understanding and Communication in Geo-Science Lessons

Shahzaib Momin (ID - 3879445)

SEC – 30 ECTS

Utrecht University

Supervisor:

Arthur Bakker

Utrecht University

Second Examiner:

Wouter R. van Joolingen

Utrecht University

Abstract

Augmented-reality Sandbox allows users to interact with 3-dimensional simulations of a river landscape. In geoscience lessons, it may facilitate the understanding of dynamic processes that consist of complex action layer(s) that are difficult to understand and structure layer(s). Students' actions play crucial role when learning through Sandbox. Hence, a quasi-experimental design was used to determine how students' actions, i.e. gestures, when using Sandbox compared to those who used traditional classroom resources. 29 students were divided into Sandbox group (who used sandbox as resource during learning activity) and Paper group (who used flip-chart paper and pen as resource). After learning activity, students had to explain one of the dynamic processes on the resource they had used. The explanations were recorded for speech-gesture analysis. On average, there was no significant difference in numbers of structure or action gestures produced by two groups. Qualitative analysis of videos and pre- and post-tests did not reveal any difference between groups' understanding of dynamic processes. It was found that Paper group used more deictic (pointing) gestures ($t(23) = 2.66$, $p = .014$, $d = 1.06$). Difference in number of iconic (semantic) gestures was not significant, but a medium effect size was observed ($d = 0.66$). Further qualitative analysis suggested that Paper group often used pointing gestures to refer to structures and locations. In contrast, Sandbox group often used iconic gestures that represented shapes to refer to same structures and locations. This effect can be attributed to the environment sandbox creates which allows users to perceive structures and locations on landscape in various ways. Hence, sandbox makes more types gestures available to students when communicating.

Keywords: dynamic systems; embodiment; learning ; gestures; action; geography

Introduction

Technological advancements have brought significant changes in education in past few decades and have affected both the pedagogical and organizational (maintaining attendance, students' profile, etc.) undertakings of a classroom. Technology can enable an environment where students have a greater share of responsibility in learning, are more and better engaged when using devices, and hence have a good share of autonomy in the classroom (Chandra & Lloyd, 2008; Hall & Higgins, 2005; Laird & Kuh, 2005). A greater autonomy for students is desirable because increased autonomy relates to increased motivation, increased motivation can lead to increased time on task, which eventually can lead to additional increases in learning outcome (Ryan & Deci, 2000). However, often with emergence of new technology comes the challenge of successfully implementing it to support students' learning; without appropriate teacher professionalization, technology can fail to serve its potential or in some cases can cause hindrances during lessons. To those working in education, especially the teachers, it may not be a surprise that sometimes technology is introduced for its novelty and attractiveness with little to no investigation of its impacts on the teaching and learning processes. When it comes to novelty and attractiveness, the Augment Reality Sandbox (henceforth referred to as **ARS**, see Figure 1), a relatively new tool that can be used mainly in geography lessons, checks all the boxes. In the past few years, ARS has been introduced at various museums and schools around the world and has proved to be a great source of attraction: the LakeViz3D institutions reported that "users often stay at the sandbox for more than 20 minutes (and sometimes more than an hour), far exceeding common dwell times at single exhibits" (Reed et al., 2016). However, does the ARS have any impact on students' learning? On the surface, ARS seems to have great potential; it allows users to visualize the landscape in 3-dimenesions; contour lines in 3-dimensions are much

Figure 1 - Screenshots of augmented reality sandbox (ARS) at International School Hilversum

easier to understand than on a piece of paper; the user can also replicate geological processes and make alterations in real-time to replicate change over time. However, building and implementing ARS is expensive (~1500 euros for one box) and time consuming. Its limited size, even when upscaled by compromising the quality, can effectively engage no more than ten students at one time. This means that lessons with ARS naturally take more time than other teaching techniques (such as direct instruction). A cost-benefit analysis becomes crucial, especially for schools with limited budget. In such an analysis, the impact of using ARS on students' understanding becomes quite crucial as this is an important benefit we desire in a classroom. To that end, little research has been done. In their poster for the conference held by European Association of Geographers, Booden and Goßens (2017) presented their study of two year 7 classes, one learning with ARS and the other learning without ARS. They found that ARS had a positive motivational effect but there was no significant difference in test scores of the two classes. However, their findings only focus on assessing students' understanding through pre- and post-tests. The study does not take into account that students' understanding can also manifest through their gestures. Roth (2001) cites various studies and experiments that verify gestures to be as important and, in some cases, more important than speech (or written words) because they often convey meaning that words fail to convey. This is especially true when spatial and temporal information (like giving directions) is being communicated. In the context of ARS, gestures can have significant role in the teaching/learning process as well as in communicating what students may have learned. This is because interaction with ARS requires users to use their hand movements. From the perspective of embodied cognition, these hand movements can become an essential part of cognition. In this study, we investigate how the gestures of students who interact with ARS compare to the gestures of students who learn without ARS. If using ARS leads to a significant difference in number and types of gestures produced, we can further analyse these gestures to see if they reveal any significant difference in students' learning. Positive results may give an insight into how ARS promotes embodied cognition. We follow the model used by Kang and Tversky (2016) who investigated role of gestures in communicating the understanding of dynamic systems (systems that involve change over time as opposed to static systems). The rationale for using this model is that the authors investigated the *structural* layer and the *action* layer of a dynamic system (discussed later) and found that when gestures are used participants developed a better understanding of the action layer, which is often more difficult to comprehend. Since many of the processes in geography that can be simulated on ARS are dynamic processes, we can investigate the gestures produced by students using this model. By situating the ARS in the context of embodied cognition and using gestures to assess students' understanding, we aim to investigate if ARS facilitates additional learning gains when learning about dynamic geoscience processes.

Theoretical Framework

AR-Sandbox

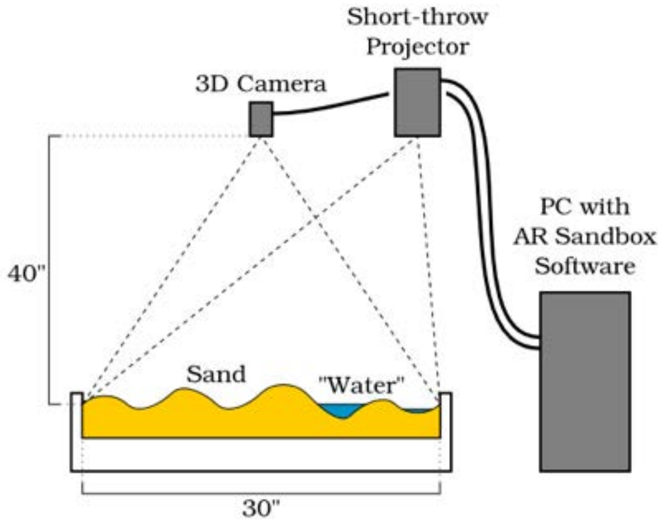


Figure 2- The arrangement of projector and sensor to project colours over sand. Retrieved from UC Davis' manual for construction of AR sandbox, *https://arsandbox.ucdavis.edu/instructions/hardware-2/*

The ARS consists of a box of sand with a motion-sensing input device and a projector attached over it (see Figure 2). The motion-sensor shown as 3d camera in the figure, detects the distance to the sand or hands. The distance-data collected by the camera are processed in real-time by the AR Sandbox software to produce colours and contour lines according to altitude of sand. These are projected on the sand as shown in Figure 3. The software can be programmed to set the height (altitude) that resembles sea level. If the sand is at or below this height, blue colour is projected on it. Given the initial parameter for sea level, the software automatically calculates the ranges of altitudes for plateau and mountain-top and projects green and red colours for these altitudes respectively. This helps create a simulation of landscape that also has contour lines projected on it.

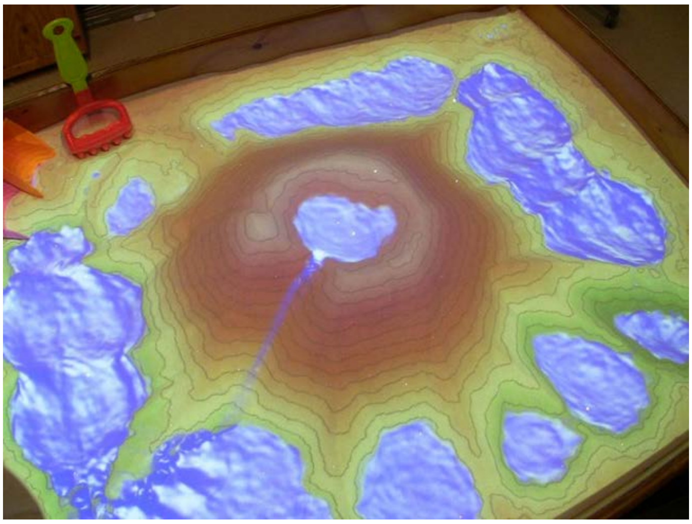


Figure 3- AR-Sandbox showing contour lines and water. Colours are projected based on the elevation of the slope (Reed et al., 2016).

When a user shapes the sand, the device perceives the changes in the configuration of sand and changes the colour of simulation and contour lines on the sand based on new altitudes, creating a visual of a landscape that is responsive to user interaction. Furthermore, when a user places her hand above the sand and closer to the motion-sensing device, the program creates virtual rain by projecting darker blue in the regions below the hand. In this situation, the hand is analogous to a cloud. The dark blue simulation of water from rain can simulate water flow that responds to the slope of the sand, and hence imitates real mechanism of water flow which can be used to represent hydrological process. Similarly, the device can be programmed to visualize and interact with the processes of volcanic eruption and lava flow (iSandBOX, 2016).

Positive effects of combining learning and play on students' motivation have been supported by various studies as students are intrinsically motivated to play (for review, see Singer, Golinkoff, & Hirsh-Pasek, 2006; Woolnough, 1994). ARS combines geoscience processes with play making it an affective and captivating tool. By its very nature, the sandbox can serve purposes that present classroom technology cannot. Visualization of the geoscience processes is quite novel and takes place in three dimensions. The hands-on interaction goes beyond point-and-click and seems more natural as we are more accustomed to using hands in our daily lives; students can use their hands to, in this particular case, interact with sand, creating and modifying three-dimensional models.

With these benefits over other classroom resources that are usually used in geography lessons, it is interesting to ask if ARS can facilitate students' comprehension of dynamic geological processes. We investigate this question in the context of embodied cognition because students' interaction with ARS using their hands is central to learning with ARS. To hypothesize the potential of ARS, we first explore the complexity of dynamic systems using Kang and Tversky's (2016) work. We then discuss embodied cognition, and why ARS seems to be a powerful tool within the context of embodied cognition. Lastly, we explore role of gestures in communication to establish that we should investigate gestures as they can reveal important aspects of students' knowledge.

Dynamic Systems

Dynamics systems entail processes that take place over time. From simple systems (like bicycle pump, heart, sea-breeze phenomenon) to complex ones (like car engine, respiratory system, plate tectonics) the school curriculum includes various biological, mechanical, chemical and other dynamic processes. The complexity of the sequence of actions and their consequences make dynamic systems difficult to understand (Kang & Tversky, 2016, p. 01). This problem of comprehending dynamic systems applies to almost all geoscience processes as many of these processes take place over large spatial and temporal scales (Reed et al., 2016).

According to Kang and Tversky (2016), "dynamic systems ordinarily have one or more structural layers and one or more layers of action" (p. 01). While the structural layer is static and consists of parts of the system (like piston, cylinder or crankshaft in an engine for a four-stroke engine,), the action layer is dynamic and entails actions that take place over time (like rotating, compressing or igniting to start an engine) and have outcomes resulting from the consequence of these actions. The authors explain that dynamic systems are not only difficult to understand but are also very difficult to represent. In particular, the dynamic action layer is hard to represent. Static graphics with arrows, sequence of still-diagrams and even animations have limitations that become problematic when representing and explaining dynamic systems (p. 02). Hence, many functions that regular classroom resources (including electronic devices) have, are not very useful when imparting understanding of dynamic systems. To this end, ARS seems to provide new ways of promoting the understanding of dynamic systems in geoscience. It not only allows students to visualize large and complicated processes that take place over long period of time, but also allows them to interact with the processes and manipulate them with their actions. Furthermore, the interaction requires particular actions in form of hand movements (either to create rain, or to change landscape). In this study two geoscience processes are included: 1) formation of an Oxbow lake and, 2) formation of a Delta. Both processes occur over a very long time and include multiple structures and actions. The structure layer comprises names of the parts of river landscape such as drainage basin, sediment deposits, distributaries, river-cliff, oxbow lake, delta, etc. The action layer consists of processes such as erosion, deposition, flow of water (speed and direction), meandering of rivers, etc. On ARS, a user can not only manipulate structure layer but also the action layer: erosion can be show by taking away or digging into sand; deposition can be show by moving sand from one place to the place where sand deposits. For this reason, ARS may serve as a very useful tool when learning dynamic systems.

Embodied Cognition

The impacts of interactions of our body and external world on cognition have been an important area of study in cognitive sciences. In contrast to the traditional view that considers mind as central for its role in information processing, and regarded perceptual and motor systems as simple input and output devices, new developments under the label of Embodied Cognition (EC) view sensory and motor functions as influential in shaping the mind (Wilson, 2002, p. 625).

While many views, some even controversial, of EC exist (for review, see Shapiro, 2019; Wilson, 2002), the arguments as well as evidence in favour of the claim that our actions play a significant role in shaping aspects of our cognition are abundant. From the evolutionary perspective, many theorists have argued that our ability to perceive evolved from our need to interact with the world. Smith and Gasser (2005) have highlighted the importance of babies' interaction with environment for the development of their intelligence. The authors argue that "the intelligence of babies resides not just inside themselves but is distributed across their interactions and experiences in the physical world" (p. 13). Through the ongoing process of acting and reacting to the environment, we developed the perception of "which object is best for hiding behind, sitting on, climbing up […]" (Hostetter & Alibali, 2008, p. 495). As elegantly put by J.J. Gibson, "We must perceive in order to move, but we must also move in order to perceive" (cited in Hostetter & Alibali, 2008, p. 496).

The term Embodied Cognition generally invokes the idea that various features of our cognition are influenced by the type of body we possess, as well as the environment within which the body interacts. However, this may lead to an implication that cognition is something separate from the body and the environment. In this regard, we look at the work of Wilson and Golonka (2013) who describe "cognition as an extended system assembled from a broad array of resources" (p. 1). In this system, the body and its interaction with environment are part of cognitive resources along with the brain: "our bodies and their perceptually guided motions through the world do much of the work required to achieve our goals, replacing the need for complex internal mental representations" (p. 1). To illustrate this, the authors discuss the *outfielder problem* in which an outfielder has to chase and catch a fly ball. In doing so, the outfielder's brain does not predict the trajectory of the ball by preforming the calculations of projectile's (ball's) motion (p. 5). Instead, the outfielder relies on the continuous visual information of ball's position and adjusts her own position when necessary. This requires no internal simulation or prediction. Using outfielder problem as one of the examples, the authors show how the cognitive resources span to brain, body and environment.

In the context of ARS, the task for students is to first understand, and then to communicate a geological process. The ARS, in comparison to paper, colour pencils, or other learning devices, adds new features to the environment that facilitates cognition. For example, the 3-dimensional visualisation of landscapes, made possible through augmented reality, resembles the real-life landscapes better than other commonly available classroom resources (for example, height maps). This makes it easier to perceive the landscape and it takes away the cognitive load of trying to imagine 2-dimensional landscapes in 3-dimensions. As users have to interact with the ARS using their hand movements, touch sensory input can serve as an additional cognitive resource and specific actions are likely to get associated with specific concepts (for example, users often dig into sand to show erosion). The cognitive load is then distributed over additional sensory resource. As discussed above, by changing the landscape user can see in real-time some of the geological processes related to water flow, thereby interacting with the structure and action layer of the process. All these features of ARS add to cognitive resources in the environment and promote interaction of body with the environment to facilitate cognition.

From Actions to Gestures.

If, as suggested above, actions play an important role in the development of one's understanding, then students' actions in form of hand movements become an important mode of cognition as students interact with the computer-simulated model of a river landscape of ARS. Do these actions facilitate any 'new' learning that is not possible without ARS? One way to investigate this is to allow students to communicate their understanding through actions, i.e. through their gestures, and analyse if these gestures reveal any added value in learning.

As such, disagreements exist on the definition of gestures. Whether all body movements (for example facial expressions) that play role in communications should be considered as gestures is still debated (for review, see Roth, 2001). However, general consensus is that hand movements made during communication are gestures. In this study, I restrict myself to role of movements of hands in communication, and only the movements that constitute a meaningful gesture (gestures, like *beats* that may facilitate communication but do not communicate any content are excluded). Since Roth's review on gesture, many studies have been conducted that support the notion that gestures are not epiphenomenal, but central in learning and communication. The idea that gestures promote as well as represent understanding has been studied extensively within the context of language learning as well as mathematics. Iverson & Goldin-Meadow (2005) investigated the role of gestures in language development in 10 children and found that gestures did not only predate but also predicted the changes in language: many lexical items that children produced initially in gesture soon became part of child's verbal lexicon. In the context of mathematics, Goldin-Meadow et al. (2001) asked participants to remember a list of words while explaining solution to a maths problem. Those who used gestures while explaining remembered significantly more items, suggesting that gestures may help lighten the cognitive load. Outside the realms of mathematics and language learning, Kang and Tversky (2016) claim that in relation to explaining (and understanding) dynamic systems, the use of gestures is "underused and understudied" (p. 2). In their study of gestures and dynamic systems, participants had to watch one of the two videos that explained the structure and workings of a four-stroke engine. While the content of the two videos was the same, one video included gestures only to portray the structure of the engine while the other included gestures to portray only the actions of the system. The participants were then asked to explain the workings of the engine. Their explanation was recorded to analyse the gestures they produced. It was found that the group that watched the video with action gestures produced significantly more coherent gestures in their explanation. In this study, similar approach as that of Kang and Tversky to investigate the impacts of using ARS on students' understanding and communication: participants' explanation of a geological process is video recorded, and their gestures are analysed. In particular, the following two research questions are formulated:

1. How do the number and types of gestures of students who have learned through ARS compare to the ones who have learned through Paper?

2. How does students' understanding of geodynamic processes developed through Sandbox compares with that developed through Paper?

Based on the theory discussed, it is hypothesized that participants using ARS should produce more action gestures, and they should be able to describe the action layer of the processes better than the group learning through paper.

Method

Participants

The participants of this study were the students of grade 9 and grade 10 at International school Hilversum that follows International Baccalaureate program. Grades 9 and 10 represent Middle Years Programme 4 and Middle Years Programme 5 respectively. The experiment took place in Teaching and Learning Lab at Utrecht University as it is equipped with cameras and mics to record participants' gestures and speech. Thirty participants (16 male) were to participate in the study. One male student left during the experiment and was not included in the study. Average age of the remaining participants (N = 29) was 15 (SD = 0.80). Grade 10 students had previously (about 8 months prior to the experiment) learnt about erosion, deposition, meandering of rivers and formation of oxbow lakes. Grade 9 students had not been taught any of the concepts that were part of the lessons in this study. The participants were divided into eight groups, four of which worked with ARS (experimental group) and other four followed a paper-based lesson (control group).

Approach and Settings

A quasi-experimental design as shown in Figure 4 was used to compare the paper-based lesson to ARS lesson. The participants were divided into two groups, a control group that was

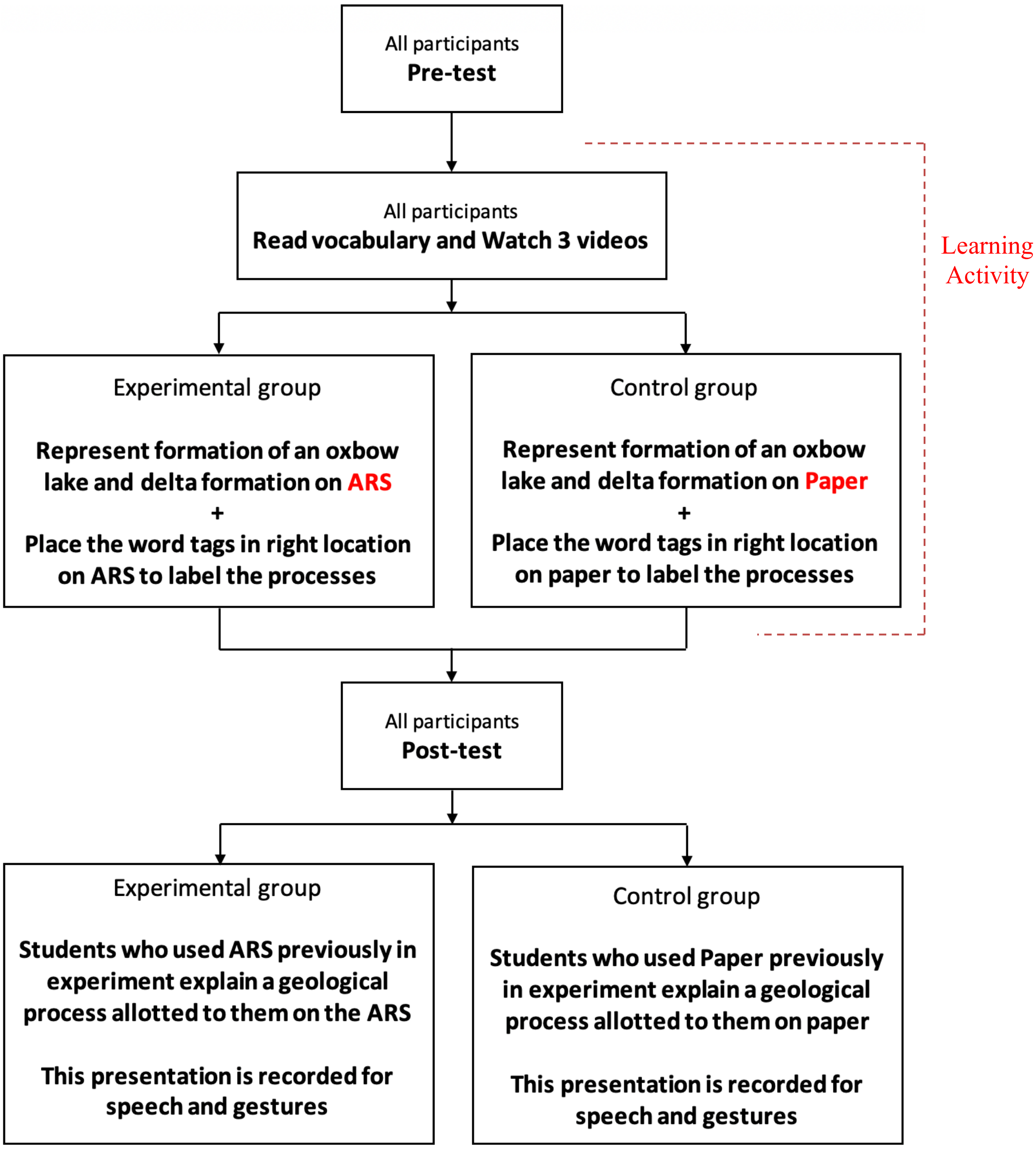


Figure 4 - Schematic overview of the experimental design

involved in paper-based lesson (henceforth referred to as Paper group) and an experimental group that was involved in sandbox-based lesson (henceforth referred to as ARS group). At the beginning of the experiment, a **pre-test** was administered. This was followed by a **learning activity** in which:

1. all participants were first given a glossary of specific action and structure words that they were going to hear in the upcoming videos,
2. all participants then watched 3 videos about meandering, formation of oxbow lake and formation of delta in that order,
3. after watching the videos, students, now working in groups of three or four, were asked to recreate the processes of the formation of oxbow lake and delta. Each group was given three illustrations to guide them and word tags that represented some of the key words from the videos. The Paper group was asked to recreate these processes through drawing(s) on a flipchart paper, while the ARS group had to recreate these by changing the landscape on ARS. After recreating, both groups were required to place the word tags on their drawing/landscape (see Figure 5). These word tags included four action words and four structure words from the videos.

After the learning activity, a **post-test** was administered. Lastly, groups were shuffled in such a way that groups of four now had two students who worked with ARS and two students who worked with paper. Groups of three had at least one student from the experimental group and the control group. Once shuffled, the students were asked to **present** to their new group members the formation of oxbow lake or the formation of delta by once again replicating the processes using the tools they had used before (hence students who used paper had to present on paper while students who used ARS had to explain on the ARS). The geological process student had to explain was allocated through lottery and it was made sure that *within a group* if one student was chosen to explain formation of oxbow lake on ARS, then the second student also presenting through ARS had to explain the formation of delta (same rule of *no repetition* applied to presentations using paper). These presentations were recorded and analysed for participants' speech and gesture.

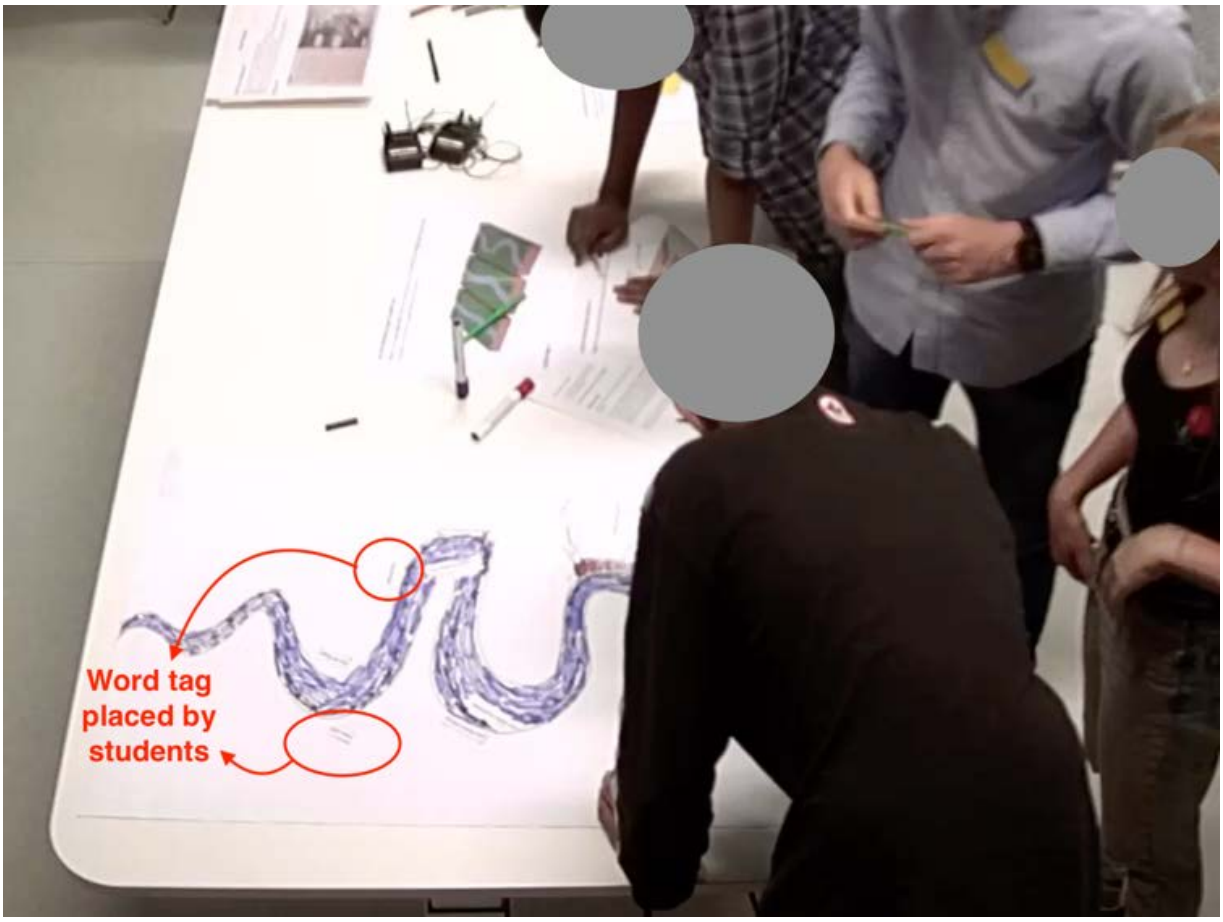


Figure 5 – Paper-group had to recreate the geological processes on paper. Word tags have been placed to identify the structure or actions of the allocated geological process

Material

The learning activities conducted throughout the experiment were designed in consultation with two geography teachers at International school Hilversum. These teachers were also present on the day of experiment to supervise some of the students. The pre-test was the same as the post-test and were also designed with the help of geography teachers. Three videos that participants watched during the learning activity were selected from Youtube and assessed and approved by the geography teachers to ensure these videos provided clear explanation of the processes and featured both the structural and action layers:

Video 1 – meandering: this video featured real-life images and cartoon-like animation to describe how and why a straight flowing river would bend (meander) over time (MinuteEarth, 2014);

Video 2 – formation of oxbow lake: this video featured only cartoon-like animation with written words (no speech) to describe how oxbow lakes are formed (Mota, 2017);

Video 3 – formation of delta: this video featured real-life images and cartoon-like animation to describe how and why two types of deltas are formed (MinuteEarth, 2015);

While videos 1 and 3 had a narrator explaining the processes, this narrator cannot be seen in the video.

Defining and Coding Gestures

The study by Kang & Tversky (2016) is used to narrow down what types of hand movements are considered as gestures. Accordingly, a hand movement is only considered a gesture when accompanied by speech to convey a particular idea. Hence, irrelevant hand movements like grooming hair with hands are disregarded. Furthermore, gestures are analysed as units where one gesture unit is defined as the "movement of hand(s) from a resting position and returning to a resting position" (p. 5). If hands do not return to resting position and hand movements are accompanied by a pause in movement or by "obvious change in shape or trajectory" these are regarded as an end of a gesture unit (p. 5). If two hands represent two different meanings, these are regarded as two gestures.

We restrict ourselves to the same type of gestures that Hostetter and Alibali (2008) have studied, i.e., representational gestures which include *deictic*, *iconic* and *metaphorical* gestures (p. 495). Other gestures like beats or interactional gestures are not included because these are used for emphasis or managing interactions, and do not reveal participant's knowledge. Moreover, during presentations that were recorded for speech-gesture analysis, only the person presenting was allowed to talk, and other interactions were not allowed.

A relevant gesture is first coded as either an **Action gesture** or a **Structure gesture** (Kang & Tversky, 2016, pp. 5-6):

- **Action gestures** show the action of a part or a process of a system, e.g., making a wavy motion with hands to resemble water flow, or raising hand/palm to show water rising, or lowering hand/palm to gesture deposition, etc;

- **Structure gestures** show the position or structure of a part, e.g., showing where the erosion/deposition occurs, or where the ox-bow lake is formed, or describing the shape of a delta or ox-box lake;

Each action and structure gesture are then further coded as a **deictic**, **iconic** or **metaphorical** gesture (Roth, 2011, pp. 370-371):

- **Deictic gestures** are used in pointing. Utterances such as such as here, there, this, that, or names of the parts of a structure accompany such gestures, e.g., pointing at the river while talking about it, or pointing at the sea to show the location where delta is formed;

- **Iconic gestures** are gestures that "depict **semantic content** directly via the shape or motion trajectory of the hand(s)", for example, drawing a circle in the air to represent a circle, or move hands in a sine/cosine curve to represent the flow of a river as waves;

- **Metaphoric gestures** use metaphor to represent the semantic content, e.g., "a mathematician holding steady one hand while she moves the other hand toward it until the two palms touch as she discusses the concept of "approaching the limit" (cited in Roth, 2011, p. 370)

Participants speech was also used to interpret gestures as speech provides the context in which gestures are made. If there was a speech-gesture mismatch or if any gesture was not accompanied by speech, then the gesture was interpreted in the context of speech that immediately preceded and followed the gesture.

Results

Pre- and post-tests

Pre- and post-tests were conducted for the Paper-based ($N = 15$) and Sandbox ($N = 14$) groups. Given the results of the study by Booden and Goßens (2017), no significant difference was expected between two groups and this was indeed the case (see Figure 6). Scores of both groups improved as the result of interventions.

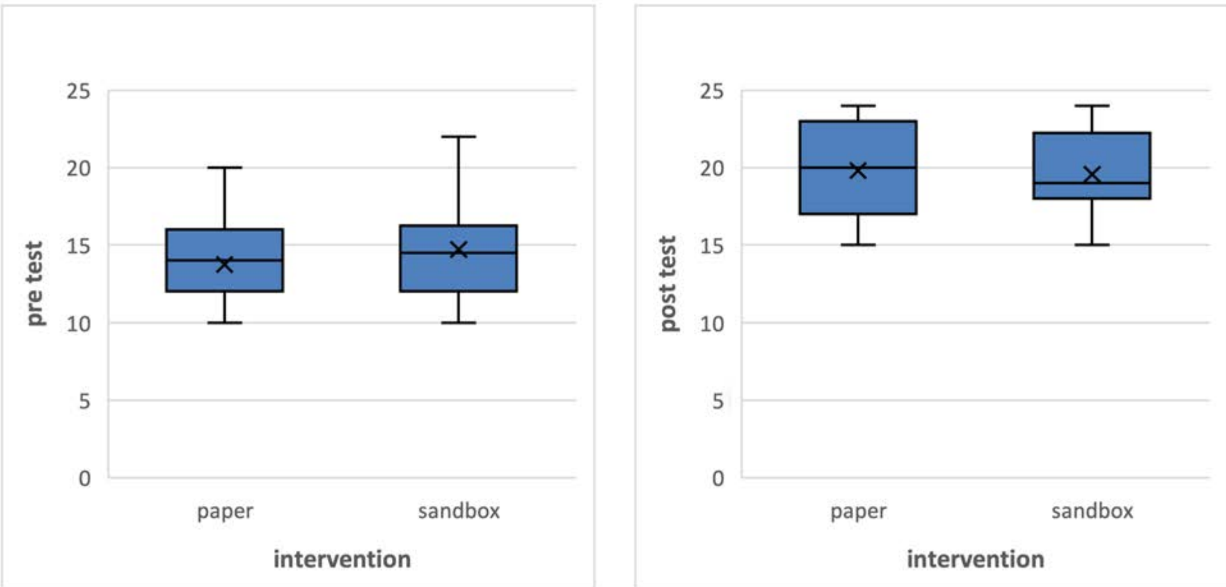


Figure 6 - Comparison of average scores of pre- and post-tests of the control and experimental groups. No significant difference was observed.

Video Analysis for gestures

When a participant presented a geological process, the presentation was to be recorded. However, four participants were not recorded due to equipment malfunction. The remaining 25 videos were analysed for gesture and speech using a software called BORIS (Friard & Gamba, 2016).

The average explanation time for Paper group was 72.08 s (N =12, SD = 21.59) which was slightly higher than the average explanation time for ARS group (N = 13, M = 68.42, SD = 32.63). An independent samples t test shows that the difference in average explanation times is not significant ($t(23) = 0.33$, $p = .742$).

A total of 429 gestures were coded. No metaphoric gestures were observed. Paper group participants were provided with a pen to represent a process through drawings. Although participants were asked to drop this pen when they were ready to present, most participants picked up the pen at some point during their presentation (see Figure 7B.2). The pen was treated as an extension to hand and its movements were also coded as gestures. 6 videos amounting to 146 gestures (34%) were randomly selected to be coded by a second coder to assess interrater reliability. There was substantial agreement between the coders k = 0.70 ($p < .01$). There was no statistically significant difference in the average number of gestures made by Paper group (M = 16.92, SD = 6.34) and by the ARS group (M =17.42, SD = 6.54) ($t(23) = -0.19$, $p = .850$).

Structure and action gestures

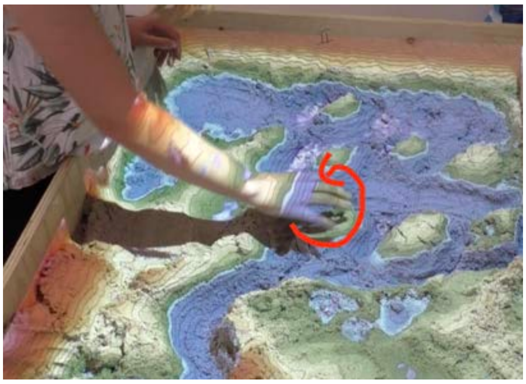
The average number of structure gestures made by Paper group (M = 8.92, SD = 4.27) was slightly higher than that of the ARS group (M = 7.25, SD = 3.57). There was no statistically significant difference in the means ($t(23) = 1.06$, $p = .301$, $d = 0.42$). Participants in the Paper group made an average of 7.46 (SD = 2.47) action gestures which was quite similar to average number of action gestures produced by ARS group (M = 7.92, SD = 2.88) (t(23) = – 0.43, p = .674, d = 0.17).

Deictic and iconic gestures

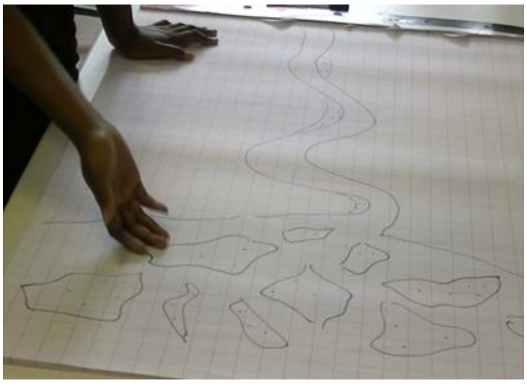
When comparing the deictic gestures produced by each group, the independent samples t test indicated a statistically significant difference (t(23) = 2.66, p = .014, d = 1.06) between the Paper group (M = 8.38, SD = 3.50) and the ARS group (M = 5.00, SD = 2.80). The effect size of d = 1.06 exceeded Cohen's (1988) convention for a large effect size (d = .50). This indicates that Paper group on average produced more *pointing* gestures than the ARS group.

On the other hand, the ARS group produced more iconic gestures (M = 10.17, SD = 3.71) than the Paper group (M = 8.00, SD = 2.83). While the difference in the average number of iconic gestures produced by the groups was not statistically significant (t(23) = – 1.65, p = .113), a medium effect size of d = 0.66 observed.

A qualitative analysis of 6 videos (3 from the Sandbox group and 3 from Paper group) was conducted to find possible causes for the effect sizes concerning deictic and iconic gestures. It was found that participants in the Paper group often used deictic gestures to point at the structure or location whereas participants in Sandbox group used iconic gestures (usually by gesturing the shape) to point at the structure or location (see Figure 7 for comparison of the two groups).

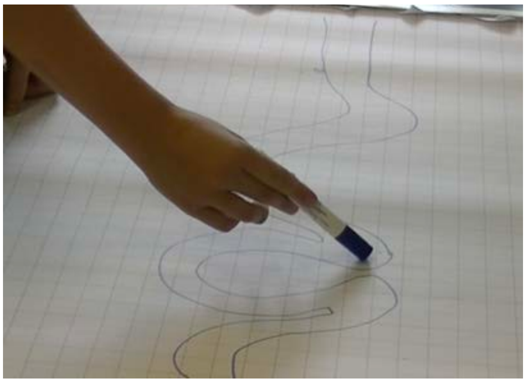


A1. The user **rotates** her hand along the boundaries of sand deposit to refer to the *'island'*



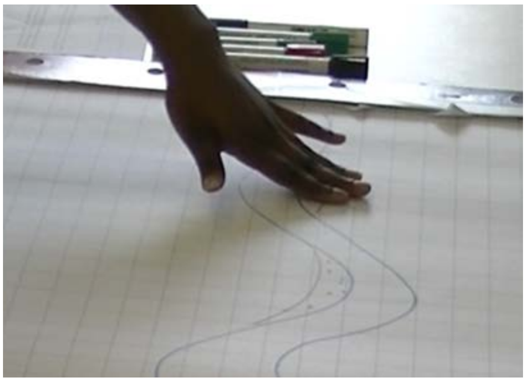
A2. The user **points** to the sand deposit to refer to the *'island'* formed during delta formation

B1. The user takes away the sand to refer to the location where bends of a river meet during oxbow lake formation



B2. The user points at the neck of the bends to refer to the location where bends of a river meet during oxbow lake formation

C1. The user moves her hand along edge of the river to show that sedimentation is deposited along that edge on the inside of the bend



C2. The user points her hand at the edge of the river to show that sedimentation is deposited along the inside of the bend

Figure *7* - Comparison of the groups show that Sandbox group often used iconic gestures to represent a structure whereas Paper group used deictic gestures to represent the same structure

Discussion

It was hypothesized that Sandbox group would produce more action gestures than the Paper group. This was, however, not the case. There was no statistically significant difference in the numbers of action gestures and structure gestures produced by the two groups. There are two possible reasons for seeing no difference: First, the lesson activity was designed in such a way that the activity on the sandbox closely resembled the activity on paper, as differences in activities might have led to differences in gestures, and we only wanted to observe the effect of Sandbox and not the activities. The learning for both groups happened through the videos, and Sandbox and Paper were used to reinforce their ideas. Hence, when reinforcing and explaining what they had learned, participants applied most of the knowledge from the videos, thereby producing similar numbers of gestures. Second, while the approach of gesture analysis is taken from Kang and Tversky, there is a significant difference in how the content is delivered to the participants in their study and to the participants in this study. Kang and Tversky's method of teaching the participants about the engine included gestures, whereas participants in this study did not learn from the gestures because the videos did not feature a real person. Using the sandbox in groups after watching the video did not have a significant impact on number of gestures students produced.

Given the large and medium effect sizes for deictic and iconic gestures respectively, qualitative analysis of videos was carried out and it was found that Paper group participants often used deictic gestures to point at structures or locations whereas Sandbox group participants used iconic gestures to do the same. This may be explained by the difference of visual dimensions and resources available to each group. The Sandbox group has 3-dimensional space available to touch and participants can easily manipulate it (e.g. sides of the river are small scale model of actual side of the river and user can introduce bends in it to show meandering). The Paper group has 2-dimensional space which offers little room for manipulation (e.g. sides of the river are lines on paper and cannot be manipulated as easily). This is in line with the embodied cognition point of view discussed earlier that helped us establish that ARS adds to the environment. In this case, the ARS allowed students to understand and represent structures not just by their location, but also by their other characteristics (mainly shape of structures). This does not imply that the Paper group did not have this understanding, but that ARS provided additional means of representation. However, it cannot be established that this additional feature in the ARS environment results in added value in cognition. While minor errors were noticed in some presentations, participants of both groups were able to successfully explain the overall processes they were allocated.

ARS is an attractive tool that has a motivational effect and makes the visualization of geological processes and structures easy. However, no additional value in terms of students' understanding was observed through gesture analysis in this study. There were various limitations that may have prevented us from finding the real potential of ARS on this front. As mentioned before, the lesson design may have limited the impact of ARS. A future study can focus on ARS as primary source of learning. For example, rather than showing a video, a teacher can teach the processes on ARS and the effects of teacher's gestures while using ARS can be studied. This approach will also bypass the issue of lack of gestures in the videos that participants had to watch in this study. It is also inferred that the processes chosen for this study were relatively easier to understand for the age group selected for this study. It might be interesting to see if the performance of the groups differs when a more complex geological process is chosen. While this study compared ARS with another teaching resource, future studies may focus on an experimental design that favours ARS, rather than choosing a compromise between two methods. Such a design may amplify the added value of ARS concerning cognition, if there is any.

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