Learning with digital maps: Does touch matter?

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Abstract

Tablet-based e-learning is praised to be an intuitive, powerful and highly motivating way to engage with digital content that needs to be learned, understood and remembered. However, there is hardly any empirical evidence yet if and why learning with multi-touch tablets is more effective when compared with more traditional mouse and keyboard based desktop applications. To test whether a multi-touch interaction provides a better learning experience and outcome than a desktop interaction, we set up a controlled experimental laboratory study with $N = 39$ participants. Our results suggest that the two learning conditions (multi-touch vs. mouse and keyboard) do not differ on any of the assessed variables (i.e., experienced fun, intuitive use, cognitive load and learning performance). Learning with a multi-touch tablet can therefore not be considered as more advantageous per se. We discuss our findings in context of intuitive interaction perspectives and cognitive load theory.

Learning with digital maps: Does touch matter?

Schools are faced with decisions, such as acquiring tablets or desktop computers (Clark & Luckin, 2013). As stated by the Horizon Report in 2012 (Johnson, Adams, & Cummins, 2012), tablet computing would become a powerful learning method and gesture-based interaction is supposed to have much positive influence in future education as well. Multi-touch tablets are most common and privately possessed and are therefore of huge potential in education (Johnson, Adams Becker, Estrada, & Freeman, 2015). It is generally assumed that multi-touch tablets are intuitive (Ardito, Costabile, & Jetter, 2014; Ingram, Wang, & Ribarsky, 2012; Schürmann, Binder, Janzarik, & Vogt, 2015), much enjoyed to interact with (van Dijk, Lingnau, & Kockelkorn, 2012; Zaharias, Michael, & Chrysanthou, 2013) and therefore better suited for learning than desktop computers (Watson, Hancock, Mandryk, & Birk, 2013).

In computer-based experimental e-learning studies, various narrated animations have been used to investigate learning outcomes (Mayer & Moreno, 2003). Such animations taught learners how causal systems work (e.g., how pumps work, how a car's braking system works, how lightning storms develop or how airplanes achieve lift). In a recent review, it was brought together that gesture-based learning studies also applied different learning domains and used various interaction methods (Sheu & Chen, 2014). Most of the studies included in this review were in domains of special education, followed by science and math. Usually, they used gesture-based devices, such as the Nintendo Wii, Microsoft Xbox Kinect or interactive whiteboards. However, compared to tablets, these systems are likely to remain niche products in classrooms (Agostinho et al., 2015).

With school-aged children, Segal (2011) reported that those who used a touch interface instead of a computer mouse applied advanced strategies for arithmetic more frequently. Therefore, they learned more efficiently which resulted in less time spent on the task. Segal argues that naturally mapped interfaces are more intuitive for the user because they allow enhanced direct manipulation. Thus, cognitive load (CL) could be reduced, resulting in better performance (Segal, 2011). A recent study with tablets showed that participants achieved higher performance when they were instructed to trace on temperature line graphs on an iPad, compared to those who studied the same materials without finger-tracing (Agostinho et al., 2015). In contrast to Segal's assumptions the experimental groups in the study of Agostinho et al. (2015) did however not differ in rated CL.

This raises the question for what reason people can learn most effectively with which interactive device. Cognitive load theory (CLT) with intuitive interaction perspectives has repeatedly been applied to explain differences in knowledge acquisition between experimental groups (e.g., Agostinho et al., 2015; Macken & Ginns, 2014; Segal, 2011). It has theoretically been argued that differences in learning outcomes between groups occur when gestures can be used, allowing a more intuitive interaction. However, conclusive evidence about the user's perceived intuitive use of interaction devices could not have been provided yet. Therefore, there is still a lack in research empirically comparing the perceived intuitive use of digital interactive products, and examining the influence on cognitive workload and performance.

To compare touch-based with mouse and keyboard based learning we conducted an experimental laboratory study, examining the intuitive use of digital maps and learning performance. Participants used Google Earth either on a multi-touch tablet or a desktop computer with mouse and keyboard. With our results we gain first insights as to how touch based interaction affects the user's experienced intuitive use, enjoyment, cognitive load and knowledge acquisition over time.

Theoretical Background

First, research on intuitive use, gesture-based interaction and direct manipulation is presented. Then, cognitive load theory with study specific expectations is explained.

Intuitive Interaction Perspectives

Intuitive use. Product designers are facing new challenges over and over again. After the claim for *usability*, which was manifested in an ISO norm (DIN EN ISO 9241-11, 1998), it was remarked that products should even be more than usable (e.g., Burmester, Hassenzahl, & Koller, 2002). Then, usability was extended to the more holistic term *user experience* (Hassenzahl & Tractinsky, 2006). Nowadays interactive systems need to be intuitive so that one can immediately start using them. Therefore, *intuitive interaction* was the latest buzzword among researchers and vendors (Ullrich & Diefenbach, 2010). Steve Jobs, for instance, claimed that the new iPad would connect users in a much more intuitive and fun way than ever before (Smith & Evans, 2010). Intuitive interaction has become of huge importance in recent research and in designing and especially promoting new user-friendly products.

The IUUI research group (Intuitive Use of User Interfaces) has been exploring the usefulness of the term *intuitive use* as a scientific concept. They defined that a technical system is intuitively usable when the user is able to interact effectively and non-consciously using previous knowledge (Naumann et al., 2007). With the aim of measuring the perceived intuitive use of products, Ullrich and Diefenbach (2010) developed the INTUI questionnaire. The INTUI model assesses four crucial components of intuitive interaction: *Gut feeling*, *verbalizability*, *effortlessness* and *magical experience*. This questionnaire can be applied to investigate differences in the reported intuitive use of interactive devices. Because the intuitive use of products is due to the physical manipulation of an interface, it is also related to the concepts of gesture-based interaction.

Gesture-based interaction and natural mapping. Yee (2009) summarized that across existing literature, there were five major criteria thought to contribute to the effectiveness of gestural interactions. They are especially relevant when gestures have been used to replace basic navigation. One of those criteria addressing the intuitive use is that applications or systems' interfaces should make clear that gestures can be used. Additionally, gestures should be obvious and intuitive in the context of relevant tasks from the user's perspective. In this way the user can focus more on the displayed content instead of thinking about how to interact with the interface.

Research with interactive gesture-based technologies draws on embodied cognition perspectives, which state that the physical manipulation of objects supports thinking and learning (Bara, Gentaz, Colé, & Sprenger-Charolles, 2004; Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004; Ramani & Siegler, 2008). Embodied interaction with gesture-based technologies involves more of our senses than traditional mouse-based interfaces, and includes direct touch and physical movement. Studies about digital devices and learning provide evidence that incorporating the haptic channel yields better learning performance (Chan & Black, 2006; Han & Black, 2011).

The Horizon Report, as part of the NMC Horizon Project, is a comprehensive research venture established in 2002 that identifies and describes emerging technologies likely to have a large impact over the upcoming five years in education around the globe (Johnson et al., 2012). For instance, in the 2012 report, it was predicted that in four to five years, gesture-based computing would move the control of computers from mouse and keyboard to the motions of the body via new input devices. This would make interactions far more natural, intuitive and embodied. Gesture-based computing would enable learning by doing and therefore facilitate the convergence of a user's thoughts with their movements (Johnson et al., 2012).

Direct manipulation. Using one's own body to interact with an interface seems not only more natural or intuitive, but also as more direct than using an additional helping device. Over thirty years ago, direct manipulation was defined as the ability to manipulate digital objects on a screen without the use of command-line commands (Shneiderman, 1983). Since then, many new devices have been designed that differ in their directness to manipulate different interfaces. Figure 1 shows how participants are zooming either directly with a two-fingers gesture or less directly with a mouse by clicking on the map's symbols.

Figure 1. Zooming with a two finger-gesture (left) and by clicking with the mouse on the map's symbols (right).

Segal (2011) defined three properties of direct manipulation that are crucial aspects for gestural interface design, which are similar to some criteria from Yee (2009). Segal differentiates between the mapping of gestures for usability purpose (*Behavioral Mapping*) and the mapping of gestures for a performance and learning purpose (*Gestural Conceptual Mapping* and *Direct-Touch Input*). Behavioral mapping refers to the mapping between cause and effect (Antle, 2007). It mainly relates to usability and is defined as the control the user has over the interaction with the interface. When users interact with an interface which has well-designed behavioral mapping, they do not think about how to manipulate the features of the interface on the screen, but can rather focus on the content. Gestural conceptual mapping refers to embodied metaphors of gestures that are mapped to the learned concept. For instance, in this study, the gesture of rotating two fingers on a multi-touch tablet is conceptually mapped to the concept of changing the maps north orientation. Direct-touch input refers to the physical action of directly touching objects on a screen rather than having a control device. This should help process abstract content and build internal representations that are more accurate (Segal, 2011).

For those intuitive interaction perspectives, the intuitive use of products relates to the use of naturally mapped gestures. One could assume that a multi-touch interaction would be perceived as more intuitive as a mouse and keyboard interaction because of the use of naturally mapped gestures. In the following section we explain why an intuitive gesture-based interaction could make knowledge acquisition more effective.

Cognitive Load Theory

As stated by Agostinho et al. (2015), CLT (Sweller, Ayres, & Kalyuga, 2011), has over the years drawn on a number of theoretical and empirical perspectives, including schema theory (Bartlett & Burt, 1933; Marshall, 1995), working memory (Baddeley, 2012), expert-novice differences (Kalyuga, 2007b), and evolutionary theory (Geary, 2008; Sweller, 2003). In education and specifically in experimental e-learning studies, CLT has also been applied to explain differences in knowledge acquisition (e.g., Macken & Ginns, 2014; Segal, 2011).

Cognitive load sub constructs. Most important for this master's thesis is that CLT distinguishes between *Intrinsic*, *Extraneous* and *Germane CL* (Sweller, van Merrienboer, & Paas, 1998; Sweller, 1988, 2010). Intrinsic CL distinguishes between external determined and internal determined intrinsic CL (Seufert, Jänen, & Brünken, 2007). External intrinsic CL is concerned with the natural difficulty or complexity of information that must be understood and the material that is to be learned. Learning the biggest cities, lakes and rivers of a country by heart is a task with less external intrinsic CL, compared to a task where they have to be learned and remembered in regard to each other on a map. Internal intrinsic CL is influenced both by the learners' prior knowledge and their already existing schemata of a given learning content. An example for having an elaborate geographical schema is having a mental picture of a country's surface with its mountain ranges, lakes and rivers or being able to imagine in which compass direction the water of a river flows.

Extraneous CL, as second component, originates through the way the learning material is presented and how it can be interacted with. Poor instructional design can lead to high extraneous CL, which is undesirable as it unnecessarily takes up working memory capacity (Kalyuga, 2007a). Since extraneous CL hinders learning, the goal in CLT is to minimize it, for example through pacing (Moreno & Mayer, 2007; Stiller, Freitag, Zinnbauer, & Freitag, 2009). If an instructional topic is fragmented into several units, the learner has control over which unit is to be displayed. Directly manipulating and selecting the required learning content also helps learners to develop an active relationship with the selected material (Evans & Gibbons, 2007). For an overview about how to reduce CL in multimedia learning see Mayer and Moreno (2003).

Germane CL as third component is also reported as learning relevant or learning related CL. It equates to the working memory capacity that is still unused and can therefore be needed for building constructions and schemata into the long-term memory. Thus, germane CL is associated with learning processes and needs to be at an optimal level for highest effectiveness (de Jong, 2010).

Expected amount of CL. In a given learning environment, CL should not exceed the capacity of the working memory as this could lead to overextension (Kalyuga, 2007a). Thus, CL should be on a level where learning is effective. In the following study, learning geographical content with digital maps and different devices is assumed to demand the following amount of CL:

The first expectation is that learning geographical content may generate a relatively high external intrinsic CL. This is assumed because different content needs to be learned separately and then interlinked to be understood in their relation to each other. Internal intrinsic CL, the prior knowledge and schemata, is presumed to vary among participants. If prior knowledge and schemata already exist, people have less of this type of load. However, intrinsic CL should be distributed equally between experimental groups.

The second assumption is that different interaction alternatives (e.g., multi-touch vs. mouse and keyboard) demand a different amount of extraneous CL. Based on intuitive interaction perspectives, it can be expected that through a non-conscious, intuitive, direct and naturally mapped interaction the extraneous CL may be reduced (Segal, 2011). Therefore, participants interacting with a tablet should have less of this type of load than participants interacting with mouse and keyboard on a desktop computer setup.

Since germane CL is relevant for learning, it is assumed that more of this type of load also means that more resources are available for building constructions and schemata into the long-term memory. Participants with high prior knowledge, with already elaborate schemata and those participants interacting with the multi-touch tablet yet may have more resources left to learn geographical content. Germane CL should therefore vary among participants that are using geographical applications with different devices.

Preliminary Study

In a preliminary study, it was our goal to investigate how people engage with different interaction methods. Therefore, we let participants use Google Earth with various devices, which they afterwards compared between each other. This preliminary study also helped to decide which devices to use in the main study.

A total of $N = 13$ psychology students attended the preliminary study. It took them about an hour for which they received course credit. They worked on practical tasks with Google Earth (e.g., “Follow the Aare until you reach Lake Biel. There, look at the St. Peter's Island from different perspectives.”) on different devices (mouse and keyboard, iPad, Leap Motion). Leap Motion is a device used with a desktop computer that senses hand movements. With that, Google Erath can be manipulated without even having to touch an interface. After each time using an interaction method for about 15 minutes, they filled out questionnaires, assessing the interaction itself and the perceived cognitive workload. The questionnaires are explained in the method section of the main study and are attached in the Appendix A. After the second and third interaction, the participants verbally compared the interaction methods between each other in an interview.

From observations it was shown that interacting with the tablet was easy from the start. However, it took them some time until they were able to interact properly with Leap Motion. Participants’ verbal feedback revealed that the multi-touch interaction was preferred rather than interacting with mouse and keyboard or with Leap Motion. Although, they reported to be familiar with the multi-touch and the mouse and keyboard interaction, they stated that interacting with the tablet would be much more logical and easy. The free-form hand movement interaction was reported to be fun but very exhausting. Therefore, we decided to let participants interact with Google Earth to learn geographical content in the main study only by tablet or by mouse and keyboard and not by Leap Motion.

Main Study Objectives

Based on CLT and intuitive interaction perspectives the present main study aims to investigate the impact of two different devices on learning. Our specific goal is to investigate if the multi-touch interaction is perceived as more fun, intuitive and direct to manipulate opposed to the mouse and keyboard interaction. Moreover, we question whether potential differences in these variables have an influence on the participants' cognitive load and ultimately on knowledge acquisition. To reach this goal, we let participants learn geographical content, using Google Earth either on a multi-touch tablet or a desktop computer with mouse and keyboard. We state the following hypothesis:

Perception-hypothesis. The interaction on the multi-touch tablet is perceived and thus rated as significantly more enjoyed, more intuitive, more direct and less cognitively demanding than the interaction with mouse and keyboard on the desktop computer.

Short-time-learning-hypothesis. Since the participants are interacting with the learning content for 30 minutes, we hypothesize a significant main effect for geographical knowledge between the first and second time of measurement. We expect that participants of both groups show higher knowledge scores in the immediate post-test than in the pre-test.

Long-time-learning-hypothesis. We further hypothesize that participants' acquired knowledge does not significantly decrease from immediate post-test to the delayed post-test, indicating a long-time learning effect.

Learning-interaction-hypothesis. Finally, we hypothesize a significant interaction effect for type of interaction and times of measurement. We expect that participants interacting with Google Earth on the multi-touch tablet gain more knowledge from pre-test to immediate post-test than participants interacting with mouse and keyboard on the desktop computer.

Method

Experimental Design

Our study had a 2 x 3 mixed design with type of interaction (multi-touch vs. mouse and keyboard) as between-subject factor and time of measurement of the geographical knowledge (pre-test vs. immediate post-test vs. delayed post-test) as repeated measures factor. Participants learning with the tablet (n = 20) were able to directly manipulate the map with their fingers, while participants in the desktop condition (n = 19) interacted with the map by using a mouse and a keyboard. Participants completed a pre-test, an immediate post-test and a delayed post-test on knowledge about Swiss rivers, lakes and cities.

Participants

A total of N = 39 participants (students: n = 33, non-students: n = 6) took part in our laboratory study. Those recruited privately (n = 18) took part in a voucher lottery. Those recruited over web applications (n = 21) received course credit (n = 8), an amount of money (n = 11) or took part in the voucher lottery (n = 2). Four participants were excluded from the analysis, one because of insufficient German language skills, two because of lack of compliance in following the instructions during the study and one participant was excluded because of technical problems during the learning session. Three of the remaining N = 35 participants did not show up for the delayed post-test session. Those participants were excluded from analysis when delayed post-test scores were analyzed. The average age of the N = 35 participants (females: n = 19) was 28.4 years (SD = 8.3).

Materials

To conduct the study, the application Google Earth (version 7.1.1) was used by half of the participants on an iPad 2 multi-touch tablet (Apple iOS 8.3, 9.7 in). The other half of the participants used Google Earth (version 7.1.2) on an iMac (Mac OS X 10.8.5) in equal frame size with an Apple keyboard and a standard mouse. A webcam by Logitech was used to record participants' think-aloud annotations and their physical interaction with the tablet's surface and content, or their physical interaction with mouse and keyboard. The recording software we used was Apple's Photo Booth (version 5.0.1) on an iMac. For a screen recording during the learning session on the desktop, the QuickTime Player (version 10.4) was used. Since the independent variable was about participants interacting with different devices, all further instruction materials, questionnaires and tests were printed on paper and not provided on screen to avoid unwanted influence on the dependent variables.

The application Google Earth as we used it showed the landscape, city names, demarcations of countries and districts and their labels. For this study, we additionally created routes to highlight the waterways of Switzerland and polygons of the lakes associated with the rivers to highlight their form and geographical location in the country. The rivers and lakes were labeled with placemarks and enriched with additional information about the biggest cities and the most important characteristics of the lakes, rivers and channels. Further, we also created placemarks to point out key places like the source of the river, the inflow and the estuary. An example can be seen in Figure 2.

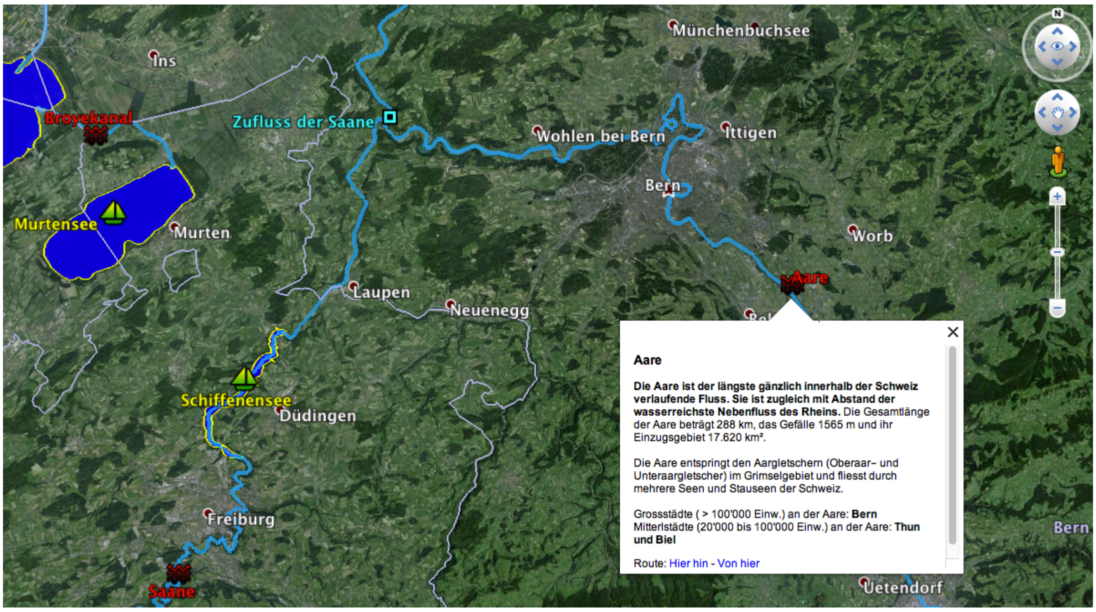


Figure 2: The enriched map on the computer with routs, polygons and placemarks.

Manipulation: Interaction Device

The interaction devices can be described by the participants' physical manipulation of Google Earth. Interacting with an iPad is different than with a mouse and a keyboard. *Pinching*, *navigating*, *zooming*, *rotating* and *tilting* are the five different input commands that are relevant when interacting with Google Earth. For those input commands, there are limited ways with a multi-touch tablet, whereas there are many different ways to interact with a mouse and keyboard on a desktop computer. For instance, moving one finger around another on the touch screen rotates the map. Comparatively, the map can be rotated by spinning the scroll wheel on the mouse forwards (rotating clockwise) and backwards (rotating anticlockwise), while the cmd-key on the keyboard is hold down. Table 4 in the Appendix B shows various differences of the five relevant input commands.

Measurement

Enjoyment and perceived competence. Two out of four dimensions of the short scale of intrinsic motivation (Wilde, Bätz, Kovaleva, & Urhahne, 2009) were used to asses participants' *interest and enjoyment* and their *feeling of competence*. Both dimensions consist of three items (e.g., "I enjoyed the interaction with Google Earth"). Participants had to indicate their level of agreement by means of a 5-point scale ranging from 1 (*is not true*) to 5 (*is completely true*). The items of these two dimensions can be found in Appendix A.

Perceived intuitive use. The INTUI (Ullrich & Diefenbach, 2010) was used to asses the perceived intuitive use of the interaction with four discrete components: Gut feeling, verbalizability, effortlessness and magical experience. In addition to the four components, a single item asks about overall *perceived intuitiveness*. Each question was to be answered on a 7-point scale between two bipolar statements (e.g., "Using Google Earth was inspiring" vs. "... was insignificant"). The questionnaire can be found in Appendix A.

Perceived level of direct manipulation. Deduced from theoretical assumptions (Segal, 2011), 6 items were created to ask about the perceived level of direct manipulation. Direct manipulation is a construct comprised by three main components *perception*, *cognition* and *motoric input*, as well as their interplay *motor cognition*, *sensory cognition* and *sensorimotor*. Perception asks whether the observation of the map changes is lagging-free. Cognition refers to the difficulty of remembering how to interact with the map. Motoric input means the physical effort when interacting with the map. The accordance between the true motoric interaction with the map and ones own expectations over the input commands is expressed as motor cognition. The belief of ones own control over map changes is expressed as sensory cognition. And the accordance between the observation over the map changes and the way the map was supposed to be manipulated is labeled as sensorimotor. For all items a 6-point scale ranging from 1 (*do not agree at all*) to 6 (*agree completely*) was used. The internal consistency was good with Cronbach's $\alpha = 0.86$. The six items used can be found in Appendix A.

Cognitive load. To measure CL, the short version of the NASA-TLX (Hart & Staveland, 1988) with 6 items and scale range from 1 to 20 was adapted and translated from English to German. In terms of interacting with Google Earth, the items asked about *perceived mental demand*, *physical activity*, *time pressure*, *task performance*, *mental effort for successful task-fulfillment* and *frustration level*. The internal consistency was acceptable with Cronbach's $\alpha = 0.76$. The questionnaire can be found in Appendix A.

Knowledge. Four tests were applied to measure participants' knowledge in geographical areas chosen for this study. Test *A* showed outlines of 11 Swiss lakes that needed to be named. The lakes were neither presented embedded in a country map nor in their size ratio. This was done to see if participants can remember the lakes only by its characteristic shape. Examples of outlines of three important Swiss lakes are in Figure 3.

Figure 3: Three examples of Swiss lakes that needed to be named in Test *A*. From left to right: Lake Lucerne, Lake Zurich and Lake Constance.

Test *B* showed 16 parts of Swiss rivers and again the 11 Swiss lakes now embedded in the country map (see Figure 4). Test *C* showed 30 major cities along the rivers and lakes on the map. To guide participants to learn and explore where the relevant lakes, rivers and cities are, they had task sheets with sub-questions to work on during the learning session (see Procedure). Test *D* was a gap text with 36 gaps to fill in, which asked about this content that was also learnt trough the sub-questions of the task sheets. All tests and task sheets used in the study are presented in Appendix A.

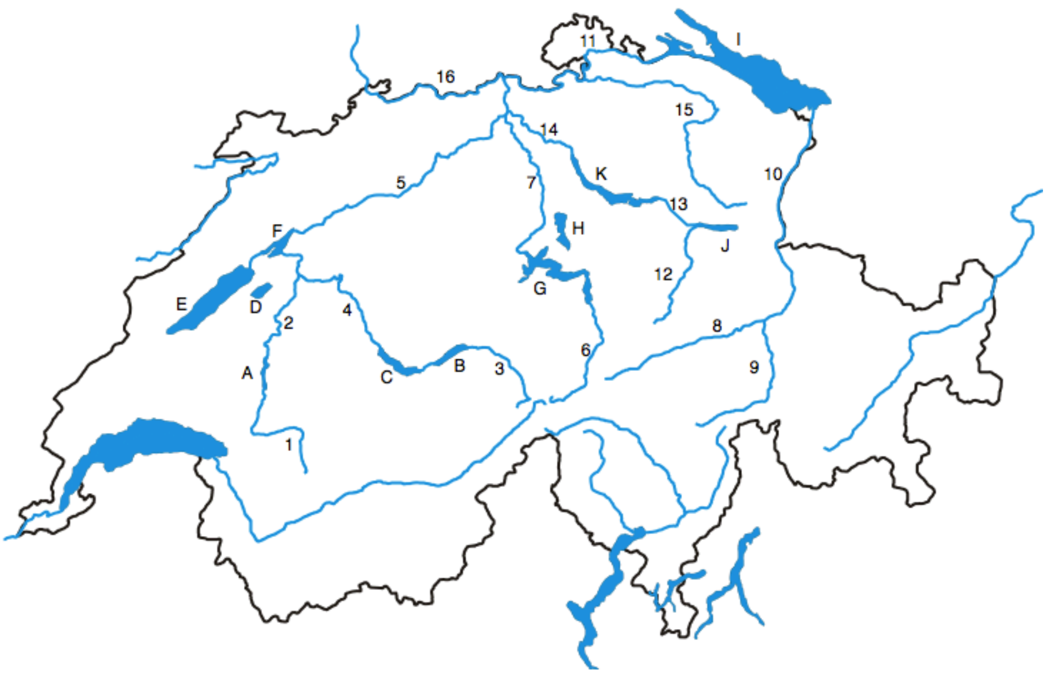


Figure 4: Test *B* with lakes (marked with letters) and rivers (marked with numbers) that needed to be named.

In all tests, participants were given one point for each correct answer, half a point for each partly correct answer and no point for each incorrect answer. The internal consistency for the pre-test (mean value from test *A* and *C*) was good with average Cronbach's $\alpha = 0.82$, excellent for the immediate post-test (mean value from tests *A, B, C* and *D*) with average Cronbach's $\alpha = 0.9$, and good in the delayed post-test (mean value from tests *A, B, C* and *D*) with average Cronbach's $\alpha = 0.81$. Test-retest correlations were good to very good with $r = 0.88$ between pre-test and immediate post-test, $r = 0.92$ between immediate post-test and delayed post-test and $r = 0.87$ between pre-test and delayed post-test.

Qualitative measurements and covariates. With notes, screen-, audio- and video recordings of hand- and finger-movements qualitative data were gathered. Further, data about self-reported general knowledge in geography, places where participants grew up and have lived in, as well as situations and hobbies where participants came in contact with maps were collected. Moreover, demographic variables age, gender, occupation and education were assessed. However, due to insufficient time, qualitative data and covariates were not all yet systematically evaluated. All questionnaires used in the study can be found in Appendix A.

Procedure

The first part of the study was structured in a pre-test session, a consistent 30 minutes learning intervention and an immediate post-test session, which took the participants in total 75 minutes. The second part of the study, the delayed post-test session, was 5 to 11 days later and took about 15 minutes. Participants were observed one by one in each session under controlled conditions with the same technical setup per condition. Figure 5 displays the study's procedure. The following reported study materials are also presented in Appendix A.

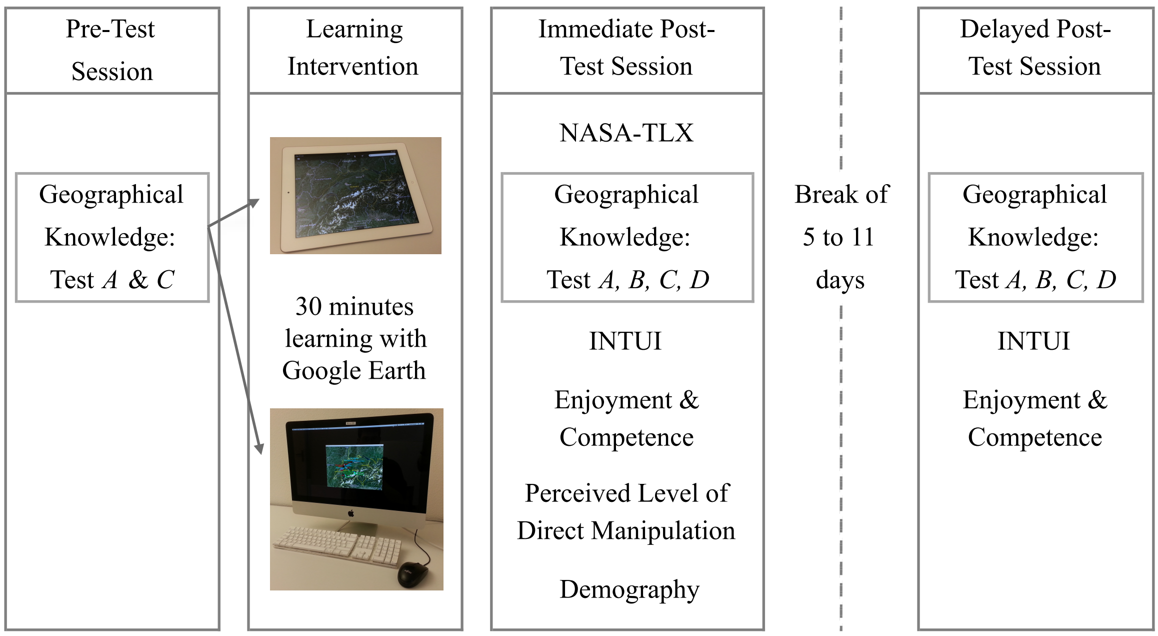


Figure 5. The study's procedure with geographical knowledge tests and questionnaires.

Pre-test session. First, the participants were explained the study's procedure and filled out the study's consent. To control the level of prior knowledge in Swiss geography, they then estimated their geographical knowledge and filled out test *A* and *C*. They got two, respectively five minutes time for those tests. Measuring the prior knowledge was also important to see increases in learning, as both tests were to be filled out after the learning intervention and again after 5 to 11 days in the delayed post-test session. After random assignment to either the tablet- or desktop condition, participants then described briefly how they would expect to interact with Google Earth on their device.

Learning intervention. With an instruction manual, participants were first allowed to practice navigating, zooming, rotating and tilting on their device for up to five minutes with the map of New Zealand. Before the actual learning intervention started, participants read a thematic introduction sheet about the Swiss water system. Participants were then guided by four task sheets to make sure they could reach the learning goals (see Table 1). While following the river from its source, they were asked to remember the lakes and biggest cities. In water flow direction, they got additional written sub-questions to respond to (e.g., “Which two little rivers combine to the Reuss?”). Four Swiss water systems on four different task sheets were to be learnt separately: (a) The Reuss, (b) the Linth and the Limmat, (c) the Aare and the Saane and (d) the Thur and the Rhine, in which all the water flows from the previous mentioned rivers. The learning period took about 30 minutes.

Table 1

Learning Goals

Rivers	16 selected parts of rivers whose water sooner or later flows into the Rhine.
Lakes	11 selected lakes related to the 16 rivers, which were to be remembered by their characteristic shapes or embedded in the country map.
Cities	30 of the biggest and most important cities along these rivers and lakes.
Facts	Some important characteristics about the lakes and rivers.

Immediate post-test session. This session consisted of questionnaires and geography tests. Right after the learning intervention, participants filled out the translated and adapted short version of the NASA-TLX (Hart & Staveland, 1988). This questionnaire was immediately filled out after the intervention so CL could not have been influenced by the post-tests. Then, the participants completed tests *A*, *B, C and D* to see whether they gained any new knowledge in Swiss geography and its water system through the intervention (short-time learning). They got two minutes for test *A* and five minutes each for test *B*, *C* and *D.* Then, they rated the provided statements of the INTUI questionnaire (Ullrich & Diefenbach, 2010), of two dimensions of the short scale of intrinsic motivation (Wilde et al., 2009) and of the perceived level of direct manipulation. Beside some demographical variables, participants closed the first part of the study by stating where they grew up, have lived in and in what situation they came across geographical maps.

Delayed post-test session. Participants came again to do the geographical knowledge tests and to fill out the questionnaires 5 to 11 days after the first part of the study. This delayed post-test session took about 15 minutes and was conducted to investigate knowledge acquisition over time (long-time learning) and changes in perceived interaction with Google Earth. They first had to state whether they interacted with some of the learning content since the first meeting and if so, how often and on which device they refreshed their knowledge. Following this, they filled out tests *A, B, C* and *D* again. This time there was no time restriction, participants were just told not to think for too long and to go on if they could not remember. Then, they had to write down how they navigated, rotated, zoomed in and out, and how they tilted the map with their assigned device in the learning intervention. They rated again the provided statements of the INTUI questionnaire (Ullrich & Diefenbach, 2010) and of two dimensions of the short scale of intrinsic motivation (Wilde et al., 2009).

Results

All data was checked to ensure that it met the required conditions for the specific statistical tests and whether it was normally distributed. For statistical testing, an α-level of .05 was used. Our final testing sample consisted of N = 35 (tablet condition: n = 18) participants. Due to study dropouts there are only data of N = 32 participants in the delayed post-test conditions (tablet condition: n = 15).

Subjectively Perceived Measurements

Enjoyment and perceived competence. Against our perception-hypothesis, participants in the tablet group perceived the interaction, neither after the immediate post-test (IPT) nor about one week later after the delayed post-test (DPT), as more enjoyable than those in the desktop group with IPT: $F(1,33) = 1.86$, $p = .182$, $\eta_p^2 = 0.05$, and DPT: $F(1,33) = 0.81$, $p = .377$, $\eta_p^2 = 0.03$. Moreover, those interacting with the tablet did not feel more competent after any of the post-tests compared to the participants in the desktop group with IPT: $F(1,33) = 0.07$, $p = .796$, $\eta_p^2 < 0.01$, and DPT: $F(1,33) = 0.53$, $p = .473$, $\eta_p^2 = 0.02$. Table 5 in the Appendix B shows descriptive data for both groups and times of measurement.

Perceived intuitive use. After the immediate post-test only the dimension verbalizability with $F(1,33) = 4.99$, $p = .032$, $\eta_p^2 = 0.13$, and after the delayed post-test only magical experience with $F(1,30) = 4.26$, $p = .048$, $\eta_p^2 = 0.12$, turned out to be perceived significantly higher by the tablet group than the desktop computer group. Inconsistent with our perception-hypothesis, all other dimensions were not perceived differently between the groups, neither immediately after the learning session with $F(1,33) < 2.18$, $p > .149$, $\eta_p^2 < 0.07$, nor about a week later with $F(1,30) < 0.62$, $p > .440$, $\eta_p^2 < 0.03$. Table 2 shows descriptive data for both groups and times of measurement.

Table 2

Perceived Intuitive Use, measured with the INTUI Questionnaire

	Immediate Post-Test		Delayed Post-Test	
	Multi-Touch Tablet (n = 18)	Desktop Computer (n = 17)	Multi-Touch Tablet (n = 17)	Desktop Computer (n = 15)
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Effortlessness	5.86 (0.97)	5.36 (1.15)	5.89 (0.89)	5.77 (8.85)
Gut Feeling	4.35 (1.44)	4.53 (1.38)	4.49 (1.04)	4.80 (1.24)
Magical Experience	4.24 (0.92)	3.93 (1.01)	4.50 (0.90)	3.82 (0.97)
Verbalizability	6.11 (1.17)	5.16 (1.35)	5.27 (1.70)	4.96 (0.87)
Intuitiveness	6.33 (0.59)	5.82 (1.33)	6.12 (8.86)	5.93 (0.88)

Note. Scale ranges from 1 to 7.

Perceived level of direct manipulation. Against our hypothesis the participants in the tablet group perceived the manipulation of the interface not to be more direct than those in the desktop group with $F(1,33) = 0.35$, $p = .560$, $\eta_p^2 < 0.01$. Moreover, no significant differences between the groups on any item was found with $F(1,33) < 1.60$, $p > .214$, $\eta_p^2 < 0.05$. Table 6 in he Appendix B shows descriptive data for both groups.

Cognitive load. Inconsistent with our perception-hypothesis, the participants in the tablet group perceived the interaction not to be less cognitively demanding than those in the desktop group with $F(1,33) = 0.05$, $p = .830$, $\eta_p^2 < 0.01$. In addition, CL was compared between the experimental groups for each item separately. No significant differences between the groups on any item was found with $F(1,33) < 1.62$, $p > .212$, $\eta_p^2 < 0.05$. Table 3 shows descriptive data for both experimental groups.

Table 3

Perceived Cognitive Load, measured with NASA-TLX

	Multi-Touch Tablet (n = 18)	Desktop Computer (n = 17)
	M (*SD*)	*M* (*SD*)
Mental Demand	7.00 (4.81)	8.82 (5.03)
Physical Activity	5.94 (4.37)	4.59 (3.64)
Time Pressure	8.83 (5.50)	7.53 (4.26)
Task Performance	8.83 (4.40)	8.35 (3.46)
Mental Effort	7.44 (4.70)	9.41 (4.46)
Frustration Level	4.50 (3.82)	5.18 (3.84)
Average CL Score	7.09 (3.26)	7.31 (2.73)

Note. Scale ranges from 1 to 20.

Knowledge Acquisition

First, percentage scores for each test and participant were calculated in order to compare the test performance between the experimental groups over time. With those percentage scores we then calculated the total test scores for pre-test, immediate post-test and delayed post-test. The pre-test score was calculated with the mean percentage scores of test *A* and *C*, the immediate post-test and delayed post-test scores were calculated with the mean percentage scores of tests *A, B, C* and *D* per time of measurement. Further, to investigate the increase in knowledge we calculated percentage scores with the mean percentage score difference between immediate post-test and pre-test (short-time learning) and between delayed post-test and pre-test (long-time learning). Table 7 in the Appendix B shows descriptive data of these percentage scores. Figure 6 displays the improvement in measured knowledge for both groups. The means of both groups increased equivalently from pre-test to immediate post-test and stayed about stable to the delayed post-test.

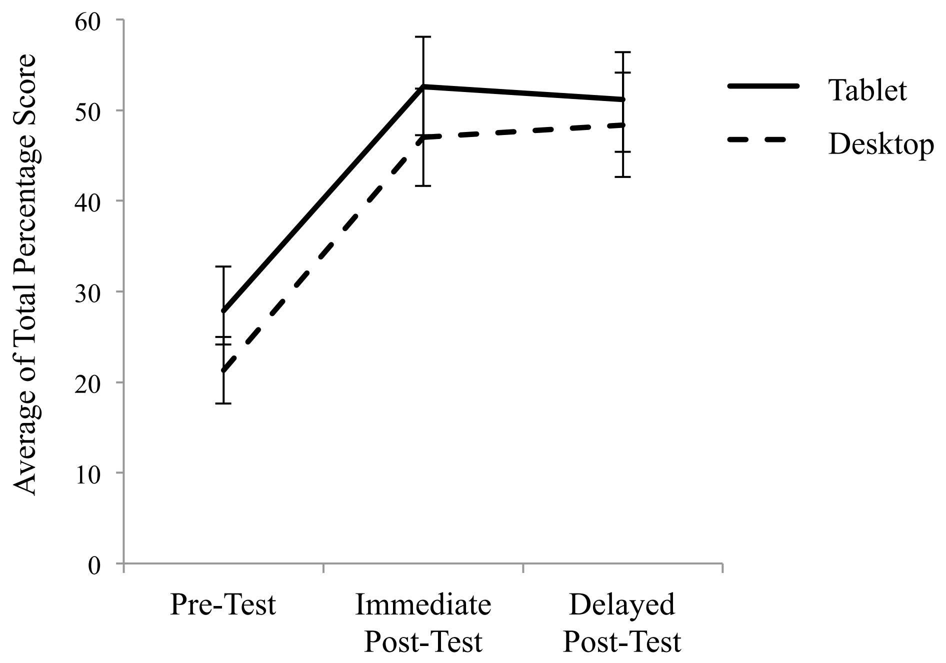


Figure 6. Average percentage scores of geographical knowledge. Error bars denote mean standard errors.

First, a two-way analysis of variance (ANOVA) was conducted with interaction device as between-subject factor with two levels (multi-touch tablet and desktop computer) and time of measurement as within-subject factor with three levels (pre-test, immediate post-test and delayed post-test). Inconsistent with our hypothesis, there was no significant interaction effect for objective knowledge acquisition between the experimental groups with $F(2,60) = 0.10$, $p = .909$, $\eta_p^2 < 0.01$, and no significant main effect between those groups with $F(1,30) = 0.16$, $p = .694$, $\eta_p^2 < 0.01$. However, consistent with our hypothesis, there was a significant main effect in the factor time of measurement with $F(2,60) = 129.84$, $p < .001$, $\eta_p^2 = 0.81$.

In addition, we calculated main contrasts to test whether the participants across both experimental groups gained significantly more knowledge over time. Consistent with our short-time-learning-hypothesis, this revealed a significant and large contrast effect between pre-test and immediate post-test with $F(1,30) = 159.81$, $p < .001$, $\eta_p^2 = 0.84$. Consistent with our long-time-learning-hypothesis, no significant contrast effect between immediate post-test and delayed post-test was revealed with $F(1,30) = 0.10$, $p = .760$, $\eta_p^2 < 0.01$, indicating that the acquired knowledge did not decrease but remained stable.

A one-way ANOVA then followed to test specific differences in average increased knowledge between experimental groups. For this analysis, we used the short-time and long-time learning scores. Against our learning-interaction-hypothesis, this ANOVA revealed no significant difference for objective measures of improvement between the experimental groups in short-time learning with $F(1,33) = 0.06$, $p = .811$, $\eta_p^2 < 0.01$, and long-time learning with $F(1,30) = 0.05$, $p = .834$, $\eta_p^2 < 0.01$.

Further Results

Gender differences. Compared to male participants (n = 16) females (n = 19) often reported that they were not good in Swiss geography and that the tests were difficult. Post hoc independent sample t-tests then revealed that male participants rated their general knowledge in geography after the immediate post-test significantly higher with $t(32) = 2.20$, $p = .035$ (two-tailed), $r = 0.35$, and after the delayed post-test as marginal significantly higher with $t(30) = 1.79$, $p = .084$ (two-tailed), $r = 0.30$, as female participants did. Corresponding to that in the objective learning knowledge variables we found that men showed significantly higher scores in the pre-test with $t(33) = 3.97$, $p < .001$ (two-tailed), $r = 0.55$, and in the immediate post-test with $t(33) = 2.75$, $p = .010$ (two-tailed), $r = 0.42$, and marginal significantly higher scores in the delayed post-test with $t(30) = 2.00$, $p = .055$ (two-tailed), $r = 0.33$, than women. However, women and men did not differ in knowledge acquisition over time with $t(33) = -0.37$, $p = .714$, $r = 0.06$. Table 8 in the Appendix B shows the descriptive data.

Behavior observations. Although all participants were advised to interact with Google Earth, participants' engagement did differ between each other. Most of them engaged a lot by reading, navigating and zooming the map. In the desktop computer condition however, this can be accomplished by using the mouse without any use of the keyboard. Others were only learning the written additional information and were hardly interacting with the map. They only navigated and clicked on the symbols, hardly zoomed and never rotated or inclined the map. There were only a few who rotated the map so as to look at lakes from different perspectives. Someone stated that for the study's purpose, rotating and inclining the map would not be helpful for learning the required content in this short period of time.

Discussion

Knowledge Acquisition Between Experimental Groups

Inconsistent with our learning-interaction-hypothesis the tablet group did not significantly gain more knowledge than the desktop computer group. Therefore, one needs to consider that it does not matter with which digital device people learn geography, as long as they are provided with the learning content represented in digital maps. The reason for this conclusion is that we did not find meaningful differences between the groups, neither in objective knowledge acquisition nor in the self-rated questionnaires.

Perceived interaction. Against our perception-hypothesis, the multi-touch interaction was not perceived as more fun, intuitive or more directly to manipulate as the interaction with mouse and keyboard. This stands in contrast to theoretical expectations (Agostinho et al., 2015; Segal, 2011). Only briefly after the learning interaction, the participants in the tablet group rated the dimension verbalizability significantly higher as the comparison group. This may indicate, that it is easier to describe how to interact with a tablet than with a mouse and keyboard. Further, approximately one week after the interaction, participants in the tablet group rated magical experience significantly higher than the desktop computer group. Because this was not the case immediately after the learning session, it could be that the learning experience subsequently changed. Even so, we conclude that in this study, interacting with the multi-touch tablet and the desktop computer was perceived alike because only those two dimensions from the INTUI questionnaire (Ullrich & Diefenbach, 2010) significantly differed between the experimental groups.

Cognitive load. Since no conclusive group differences in perceived interaction were found, CL probably did not differ either between the two groups. Similar to Agostinho et al. (2015), our statistical analysis did not reveal any differences between the experimental groups in the individual CL items. This means that both groups experienced about the same amount of CL. According to the discussion of de Jong (2010), Martin (2014) and Rey (2009), it has not yet been conclusive to separate the CL sub constructs (e.g., intrinsic, extraneous and germane) from each other. With our data from the CL measurement, we could not directly provide evidence about those sub constructs. One expectation however was that extraneous CL would be reduced by a more intuitive and naturally mapped interaction. Because the multi-touch interaction did not provide a more intuitive interaction, we assume that extraneous CL was about equal between the groups. This may be the case because people are as familiar with the use of mouse and keyboard as they are with the multi-touch tablet interaction, as we learned from verbal statements in the preliminary study. Because of an expected lower extraneous CL, germane CL should have been higher, resulting in more effective learning for the tablet group. We assume that the level of germane CL was about equal between the experimental groups because we did not find differences in the perceived interaction, in the rated CL items and because knowledge acquisition finally did not differ between the groups.

Learning with digital maps. For the following reason, we conclude that geographical content can be learned effectively with interactive digital maps. According to descriptive statistics, participants answered in the pre-test about a quarter and after the learning session about half of the questions correctly. Statistical analysis showed that participants of both groups gained significantly more knowledge over time, which confirms our short-time-learning-hypothesis. On average, they gained about 25% additional knowledge from pre-test to immediate post-test. Moreover, 5 to 11 days later, participants still knew as much as right after the learning took place, indicating a long-time learning effect. Although it may not seem as a very long period of time, it cannot be taken for granted that they did not forget what they have learnt yet.

Gender differences. Men rated their geographical knowledge after the learning session and 5 to 11 days later significantly higher as women did. Regarding objective measurements, female participants showed significantly lower geographical knowledge scores in the pre-test, immediate post-test and in the delayed post-test than male participants. It has already been researched and shown that males usually outperform females in geographical topics (Ellis, 2008). In our study however, they did not differ in knowledge acquisition over time, indicating that women learn geographical content on digital maps as effectively as men.

Implications

Since no group differences in perceived interaction were found, extraneous CL seemed not to differ between the two groups either. Therefore, germane CL probably did not differ between the groups and thus both gained a similar amount of knowledge. This means, that it does not matter which device we choose for learning geographical content. Whichever device is at hand we effectively can engage with the content. No new hardware needs to be bought if already tablets or desktop computers are available.

For instructors it is important to know to what extent new technologies can improve students' knowledge acquisition. Research should therefore not only focus on basic theories and cognitive research, but also examine real world scenarios on high-levels like we did in our study. Since students learn such geographical content in school, we recommend conducting experimental e-learning studies in school settings as well. We cannot make specific statements about children's perceived interaction and learning performance with our results. However, it was our primary goal to examine if learning with different devices is effective at all, which was shown with the statistical analysis. Participants showed stable geographical knowledge acquisition after learning with either interactive device.

Limitations

Participants' engagement with the map. The multi-touch interaction was not perceived as more fun, intuitive or more directly to manipulate as the mouse and keyboard interaction. Therefore, it might be true that learning does not depend on the interaction device as we discussed in the sections above. Despite this, we argue that no differences in subjectively perceived interaction could have been due to the fact that the manipulation did not work quite as expected from the preliminary study. Participants did not have to rotate and incline the map, and hardly ever used the keyboard in the main study. This might have been because of the sub tasks. If participants were advised to rotate and incline the map more frequently, as they were in the preliminary study, perceived interaction could differ between the experimental groups. Adapting the working tasks could probably induce the required behavior for observing differences between those experimental groups in their perceived interaction, cognitive load and even learning. With our study design we wanted to have a most natural learning scenario. It was our goal to let people interact with the assigned device as they would when they were learning for themselves. Our results are therefore more external valid for our learning domain.

Sample. According to CLT, both, the learner's knowledge and his already existing schemata influence internal intrinsic CL. Descriptive statistics revealed that the prior knowledge varied much between participants. Unfortunately, we only measured prior knowledge and did not control for already existing schemata. Due to participants' statements during the learning session we know that such schemata can be as important as the measured prior knowledge in the pre-test. We assume that participants with no mental picture about basic Swiss geography need first to develop some schemata (e.g., where the mountain range is located in the map, the river's flow-direction or the fact that the lake's name often correspond to the name of a big city on this lake). Participants without elaborate schemata and little prior knowledge may have been overloaded through high internal intrinsic CL and have not had enough free resources to learn the selected geographical material in this short period of time. In comparison, some participants with little prior knowledge but already elaborate schemata were able to build on those schemata and enrich them with new information. Therefore, they still had enough cognitive resources for effective learning and showed high knowledge acquisition after all. Research should consider having bigger and more homogenous samples in terms of prior knowledge and measure prior existing schemata too, to better investigate differences in knowledge acquisition between experimental groups. Long-time learning studies with more than one learning session could help to better understand the importance of knowledge over time. E-learning applications should consider the fact that the learners' knowledge and schemata may differ. Therefore, applications should adopt the tasks continuously to the learner's knowledge and behavior to make learning most effective.

Cognitive load measurement. With the applied CL measurement we could not measure the distinct CL sub constructs. Measuring CL and interpreting its items with the sub constructs is not yet elaborated though. We hope measuring the sub constructs separately will soon be possible, giving more insight into reasons for effective learning.

Non-interactive learning methods. With our experimental design we cannot know if learning with novel devices is more effective than with traditional methods, like printed maps and textbooks. Because of participants' verbal statements during the learning session and since they gained on average about 25% additional knowledge, we highly assume that learning geographical content is predisposed to be learned by interacting with a digital map. Future human-computer interaction research could draw on this attempt and compare various learning methods and devices.

Conclusion

This master's thesis investigated the effect different devices may have on perceived interaction and geographical knowledge acquisition by comparing a multi-touch tablet to a desktop-based mouse and keyboard interaction. First, it was shown that a multi-touch tablet interaction is perceived as fun, as intuitive and as directly to manipulate as a desktop computer interaction with mouse and keyboard. Second, we provided evidence against assumed differences in perceived cognitive load while interacting with those devices. The experimental groups reported the same amount of cognitive load right after the learning session. Third, by comparing the two different interaction methods and measuring performance over time, it was revealed that a multi-touch interaction does not support more effective and deeper learning than an interaction with mouse and keyboard. Inconsistent with our hypothesis, people interacting with geographical content on a multi-touch tablet gained as much knowledge as those learning on a conventional computer with mouse and keyboard. Therefore, we finally conclude that touch does not matter, but nonetheless, since the acquired knowledge remained stable over time, geographical content can be learnt most effectively on digital interactive maps.

References

Agostinho, S., Tindall-Ford, S., Ginns, P., Howard, S. J., Leahy, W., & Paas, F. (2015). Giving learning a helping hand: Finger tracing of temperature graphs on an iPad. *Educational Psychology Review*, *27*(3), 427–443. doi:10.1007/s10648-015-9315-5

Antle, A. N. (2007). The CTI framework: Informing the design of tangible systems for children. In *Proceedings of the 1st International Conference on Tangible and Ebedded Interaction - TEI '07* (pp. 195–202). ACM Press. doi:10.1145/1226969.1227010

Ardito, C., Costabile, M. F., & Jetter, H.-C. (2014). Gestures that people can understand and use. *Journal of Visual Languages & Computing*, *25*(5), 572–576. doi:10.1016/j.jvlc.2014.07.002

Baddeley, A. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology*, *63*(1), 1–29. doi:10.1146/annurev-psych-120710-100422

Bara, F., Gentaz, E., Colé, P., & Sprenger-Charolles, L. (2004). The visuo-haptic and haptic exploration of letters increases the kindergarten-children's understanding of the alphabetic principle. *Cognitive Development*, *19*(3), 433–449. doi:10.1016/j.cogdev.2004.05.003

Bartlett, F. C., & Burt, C. (1933). Remembering: A study in experimental and social psychology. *British Journal of Educational Psychology*, *3*(2), 187–192. doi:10.1111/j.2044-8279.1933.tb02913.x

Burmester, M., Hassenzahl, M., & Koller, F. (2002). Usability ist nicht alles - Wege zu attraktiven Produkten (Beyond Usability - Appeal of interactive Products). *I-Com*, *1*, 32–40. doi:10.1524/icom.2002.1.1.032

Chan, M. S., & Black, J. B. (2006). Direct-manipulation animation: Incorporating the haptic channel in the learning process to support middle school students in science learning and mental model acquisition. In *Proceedings of the 7th International*

Conference on Learning Sciences - ICLS '06 (pp. 64–70). International Society of the Learning Sciences. Retrieved from http://dl.acm.org/citation.cfm?id=1150034.1150044

Clark, W., & Luckin, R. (2013). iPads in the classroom: What the research says. *London Knowledge Lab*, 31. Retrieved from http://www.thepdfportal.com/ipads-in-the-classroom-report-lkl_61713.pdf

De Jong, T. (2010). Cognitive load theory, educational research, and instructional design: Some food for thought. *Instructional Science*, *38*(2), 105–134. doi:10.1007/s11251-009-9110-0

DIN EN ISO 9241-11. (1998). Ergonomic requirements for office work with display terminals (VDTs) -- Part 11: Guidance on usability. *Technical Report, International Standards Organization*. Geneva, Switzerland.

Ellis, L. (2008). Geography knowledge. In *Sex differences: Summarizing more than a century of scientific research* (p. 326). Taylor & Francis.

Evans, C., & Gibbons, N. J. (2007). The interactivity effect in multimedia learning. *Computers & Education*, *49*(4), 1147–1160. doi:10.1016/j.compedu.2006.01.008

Geary, D. C. (2008). An evolutionarily informed education science. *Educational Psychologist*, *43*(4), 179–195. doi:10.1080/00461520802392133

Glenberg, A. M., Gutierrez, T., Levin, J. R., Japuntich, S., & Kaschak, M. P. (2004). Activity and imagined activity can enhance young children's reading comprehension. *Journal of Educational Psychology*, *96*(3), 424–436. doi:10.1037/0022-0663.96.3.424

Han, I., & Black, J. B. (2011). Incorporating haptic feedback in simulation for learning physics. *Computers & Education*, *57*(4), 2281–2290. doi:10.1016/j.compedu.2011.06.012

Hart, S. G., & Staveland, L. S. (1988). Development of NASA-TLX (task load index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human mental workload* (pp. 239–250). Amsterdam: North Holland Press. Retrieved from http://humansystems.arc.nasa.gov/groups/tlx/downloads/NASA-TLXChapter.pdf

Hassenzahl, M., & Tractinsky, N. (2006). User experience - a research agenda. *Behaviour & Information Technology*, *25*(2), 91–97. doi:10.1080/01449290500330331

Ingram, A., Wang, X., & Ribarsky, W. (2012). Towards the establishment of a framework for intuitive multi-touch interaction design. In *Proceedings of the International Working Conference on Advanced Visual Interfaces - AVI '12* (pp. 66–73). ACM Press. doi:10.1145/2254556.2254571

Johnson, L., Adams Becker, S., Estrada, V., & Freeman, A. (2015). NMC Horizon Report: 2015 Higher Education Edition. *The New Media Consortium*, 65. Retrieved from http://cdn.nmc.org/media/2015-nmc-horizon-report-HE-EN.pdf

Johnson, L., Adams, S., & Cummins, M. (2012). The NMC Horizon Report: 2012 Higher Education Edition. *The New Media Consortium*, 42. Retrieved from http://www.nmc.org/publications/horizon-report-2012-higher-ed-edition

Kalyuga, S. (2007a). Enhancing instructional efficiency of interactive e-learning environments: A cognitive load perspective. *Educational Psychology Review*, *19*(3), 387–399. doi:10.1007/s10648-007-9051-6

Kalyuga, S. (2007b). Expertise reversal effect and its implications for learner-tailored instruction. *Educational Psychology Review*, *19*(4), 509–539. doi:10.1007/s10648-007-9054-3

Macken, L., & Ginns, P. (2014). Pointing and tracing gestures may enhance anatomy and physiology learning. *Medical Teacher*, *36*(7), 596–601. doi:10.3109/0142159X.2014.899684

Marshall, S. P. (1995). *Schemas in problem solving*. Cambridge University Press.

Martin, S. (2014). Measuring cognitive load and cognition: Metrics for technology-enhanced learning. *Educational Research and Evaluation: An International Journal on Theory and Practice*, *20*(7-8), 592–621. doi:10.1080/13803611.2014.997140

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, *38*(1), 43–52. doi:10.1207/S15326985EP3801_6

Moreno, R., & Mayer, R. (2007). Interactive multimodal learning environments. *Educational Psychology Review*, *19*(3), 309–326. doi:10.1007/s10648-007-9047-2

Naumann, A., Hurtienne, J., Israel, J. H., Mohs, C., Kindsmüller, M. C., Meyer, H. A., … IUUI Research Group. (2007). Intuitive use of user interfaces: Defining a vague concept. *Engineering Psychology and Cognitive Ergonomics*, 128–136. doi:10.1007/978-3-540-73331-7_14

Ramani, G. B., & Siegler, R. S. (2008). Promoting broad and stable improvements in low-income children's numerical knowledge through playing number board games. *Child Development*, *79*(2), 375–394. doi:10.1111/j.1467-8624.2007.01131.x

Rey, G. D. (2009). *E-Learning: Theorien, Gestaltungsempfehlungen und Forschung*. *E-Learning*. Huber. Retrieved from http://www.elearning-psychologie.de/

Schürmann, T., Binder, C., Janzarik, G., & Vogt, J. (2015). Movement transformation on multi-touch devices: Intuition or instructional preparation? *Applied Ergonomics*, *50*, 251–255. doi:10.1016/j.apergo.2015.03.004

Segal, A. (2011). *Do gestural interfaces promote thinking? Embodied interaction: Congruent gestures and direct touch promote performance in math*. Columbia University Academic Commons. Retrieved from http://academiccommons.columbia.edu/item/ac:132260

Seufert, T., Jänen, I., & Brünken, R. (2007). The impact of intrinsic cognitive load on the effectiveness of graphical help for coherence formation. *Computers in Human Behavior*, *23*(3), 1055–1071. doi:10.1016/j.chb.2006.10.002

Sheu, F. R., & Chen, N. S. (2014). Taking a signal: A review of gesture-based computing research in education. *Computers and Education*, *78*, 268–277. doi:10.1016/j.compedu.2014.06.008

Shneiderman, B. (1983). Human factors of interactive software. In A. Blaser & M. Zoeppritz (Eds.), *Enduser Systems and Their Human Factors* (Vol. 150, pp. 9–29). Springer. doi:10.1007/3-540-12273-7_16

Smith, C., & Evans, B. (2010). *Apple launches iPad: Magical & revolutionary device at an unbelievable price*. *Apple Press Info*. Retrieved September 14, 2015, from http://www.apple.com/pr/library/2010/01/27Apple-Launches-iPad.html

Stiller, K. D., Freitag, A., Zinnbauer, P., & Freitag, C. (2009). How pacing of multimedia instructions can influence modality effects: A case of superiority of visual texts. *Australasian Journal of Educational Technology*, *25*(2), 184–203. Retrieved from http://ajet.org.au/index.php/AJET/article/view/1149/397

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257–285. doi:10.1207/s15516709cog1202_4

Sweller, J. (2003). Evolution of human cognitive architecture. *The Psychology of Learning and Motivation*, *43*, 216–261. Retrieved from http://www.sciencedirect.com/science/article/pii/S0079742103010156

Sweller, J. (2010). Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educational Psychology Review*, *22*(2), 123–138. doi:10.1007/s10648-010-9128-5

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive Load Theory*. Springer. doi:10.1007/978-1-4419-8126-4

Sweller, J., van Merrienboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*(3), 251–296. doi:10.1023/A:1022193728205

Ullrich, D., & Diefenbach, S. (2010). INTUI. Exploring the Facets of Intuitive Interaction. In J. Ziegler & A. Schmidt (Eds.), *Mensch & Computer 2010* (pp. 251–260). Retrieved from http://www.researchgate.net/publication/221439784

Van Dijk, E. M. A. G., Lingnau, A., & Kockelkorn, H. (2012). Measuring enjoyment of an interactive museum experience. In *Proceedings of the 14th ACM International Conference on Multimodal Interaction - ICMI '12* (pp. 249–256). ACM Press. doi:10.1145/2388676.2388728

Watson, D., Hancock, M., Mandryk, R. L., & Birk, M. (2013). Deconstructing the touch experience. In *Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces - ITS '13* (pp. 199–208). ACM Press. doi:10.1145/2512349.2512819

Wilde, M., Bätz, K., Kovaleva, A., & Urhahne, D. (2009). Überprüfung einer Kurzskala intrinsischer Motivation (KIM). *Zeitschrift Für Didaktik Der Naturwissenschaften*, *15*, 31–45. Retrieved from http://www.archiv.ipn.uni-kiel.de/zfdn/pdf/15_Wilde.pdf

Yee, W. (2009). Potential limitations of multi-touch gesture vocabulary: Differentiation, adoption, fatigue. *Lecture Notes in Computer Science*, *5611*, 291–300. doi:10.1007/978-3-642-02577-8_32

Zaharias, P., Michael, D., & Chrysanthou, Y. (2013). Learning through multi-touch interfaces in museum exhibits: An empirical investigation. *Educational Technology and Society*, *16*(3), 374–384. Retrieved from http://www.ifets.info/journals/16_3/28.pdf

Appendix A

Geographical Knowledge Tests

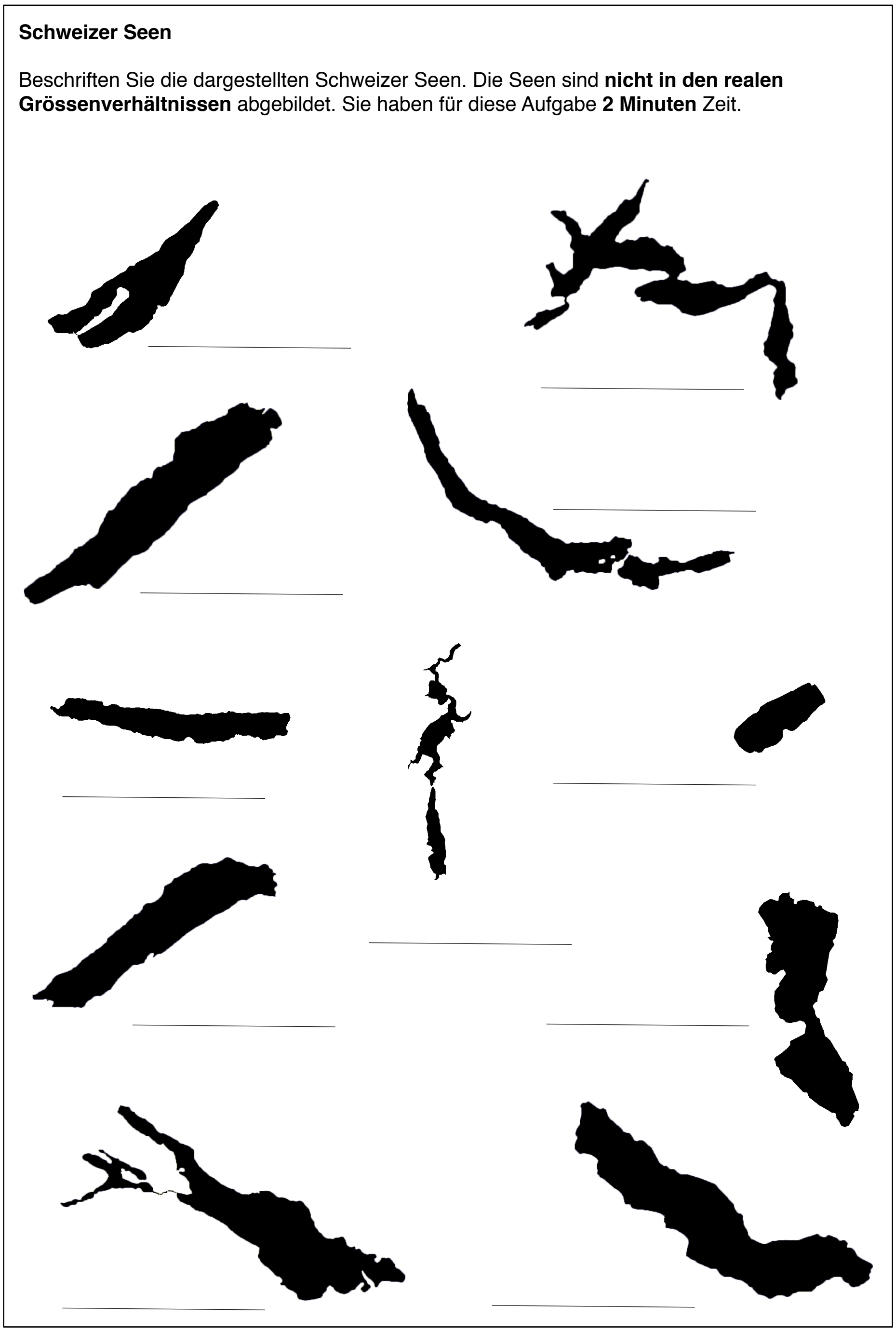
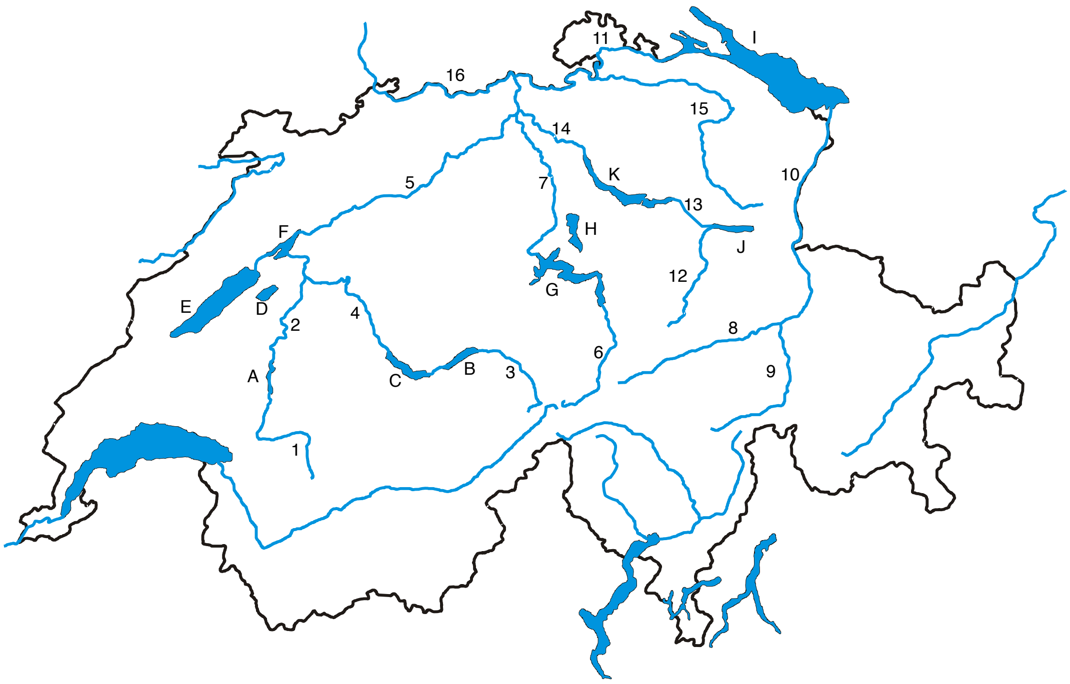


Figure 7. Test *A* of the pre-test showed outlines of 11 Swiss lakes that were neither presented embedded in a country map nor in their size ratio, to see if people can remember the lakes only by its characteristic shape. Participants did not have a time restriction in the delayed post-test.

Schweizer Gewässer

Beschriften Sie die mit Zahlen markierten Schweizer Flüsse und die mit Buchstaben markierten Schweizer Seen. Bei den Flüssen kann es auch zu **Mehrfachnennungen** kommen. Sie haben dafür **5 Minuten** Zeit.

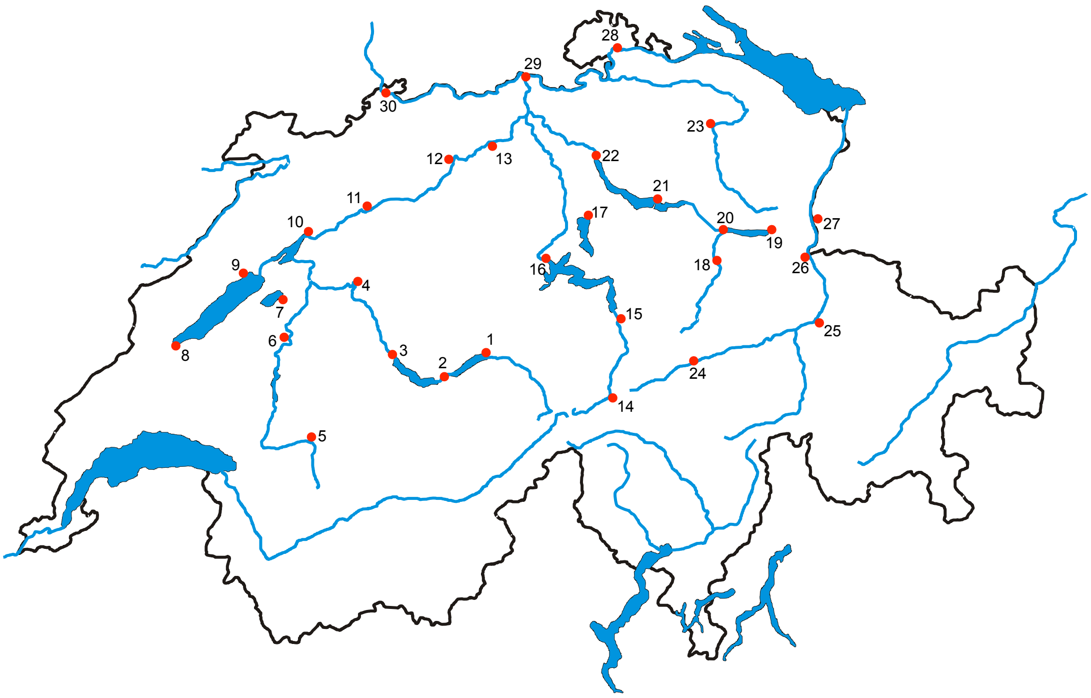


1. ______	15. ______
2. ______	16. ______
3. ______	
4. ______	A. ______
5. ______	B. ______
6. ______	C. ______
7. ______	D. ______
8. ______	E. ______
9. ______	F. ______
10. ______	G. ______
11. ______	H. ______
12. ______	I. ______
13. ______	J. ______
14. ______	K. ______

Figure 8. Test *B* showed 16 parts of Swiss rivers and the 11 Swiss lakes embedded in the country map. In the delayed post-test, participants did not have a time restriction.

Städte an Schweizer Gewässer

Beschriften Sie die 30 markierten Städte. **Überlegen Sie nicht zu lange. Gehen Sie weiter, wenn Sie etwas nicht wissen.**



1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________
8. ______________________________
9. ______________________________
10. ______________________________
11. ______________________________
12. ______________________________
13. ______________________________
14. ______________________________
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16. ______________________________
17. ______________________________
18. ______________________________
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22. ______________________________
23. ______________________________
24. ______________________________
25. ______________________________
26. ______________________________
27. ______________________________
28. ______________________________
29. ______________________________
30. ______________________________

Figure 9. Test *C* showed 30 major cities along the rivers and lakes on the map. Participants had five minutes time in the pre-test and in the immediate post-test.

Bitte vervollständigen Sie den Lückentext. **Überlegen Sie nicht zu lange. Gehen Sie weiter, wenn Sie etwas nicht wissen.**

1. Die Reuss

- Die Reus bildet sich aus der ____________(Fluss) und der ____________(Fluss).
- Die Reuss trägt den Namen ab ____________(Ortschaft).
- Die Reuss fliesst durch den ____________(See).
- Aus dem ____________(See) gelangt noch mehr Wasser über die ____________(Fluss) in die Reuss.
- Die Reuss fliesst bei ____________(Stadt) in die ____________(Fluss).

2. Die Linth

- Das Wasser der Linth stammt vom ____________ - Bergmassiv.
- Die Linth fliesst in den ____________(See) und verlässt diesen als Linthkanal.
- Der Linthkanal fliesst dann in den ____________(See).
- Aus diesem Bananenförmigen See fliesst dann die ____________(Fluss).
- Dieser Fluss fliesst schlussendlich in die ____________(Fluss).

Figure 10. First part of test *D*, that was a gap text with 36 gaps to fill in, which asked about the content that was also learnt trough the sub-questions of the task sheets.

Bitte vervollständigen Sie den Lückentext. Sie haben für diese Aufgabe **5 Minuten** Zeit. **Überlegen Sie nicht zu lange. Gehen Sie weiter, wenn Sie etwas nicht wissen.**

3. Die Aare

- Ein Teil des Wassers der Aare stammt von ___ (Anzahl) Gletschern. Und zwar von: ____ (Gletschern)
- Die Aare fliesst zuerst durch den ___________(See), dann durch den ___________(See).
- Nach der Hauptstadt fliesst die ___________(Fluss) von der linken Uferseite her in die Aare.
- Der ___________(Stausee) ist der längste Stausee der Schweiz.
- Bei Hochwasser fliesst das Wasser aus dem ___________(See) zuerst in den ___________(See) und dann manchmal sogar noch in den ___________(See). Diese Seen dienen so als Ausgleichsbecken bei Hochwasser.
- Auf der rechten Uferseite der Aare fliesst erst das Wasser der ___________(Fluss) dann der ___________(Fluss) in die Aare.
- Bei ___________(Stadt) fliesst dann die Aare in den ___________(Fluss).

4. Der Rhein

- Der Rhein bildet sich aus dem ___________(Fluss) und dem ___________(Fluss).
- Der Rhein trägt den Namen ab ___________(Ortschaft).
- Der Rhein bildet (in Fliessrichtung) zuerst die Landesgrenze zu ___________(Land), dann zu ___________(Land) und drittens zu ___________(Land).
- Der Rhein fliesst durch den ___________(See).
- In den Rhein fliessen zwei Flüsse, zuerst die ___________(Fluss), dann die ___________(Fluss).
- Bei ___________(Stadt) fliesst der Rhein aus der Schweiz.

Figure 11. Second part of test *D*, that was a gap text with 36 gaps to fill in, which asked about the content that was also learnt trough the sub-questions of the task sheets.

Introduction Material

Bedienung von Google Earth

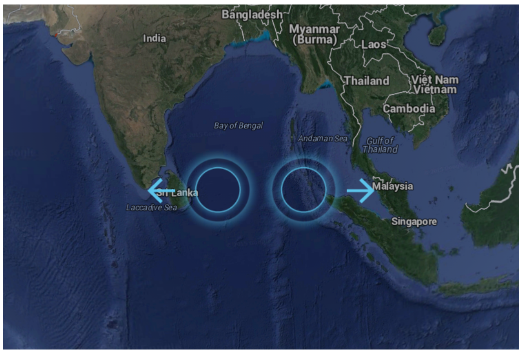
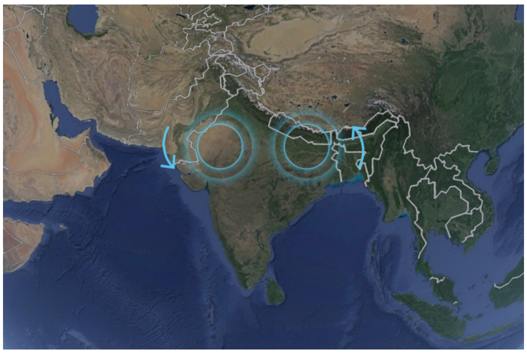
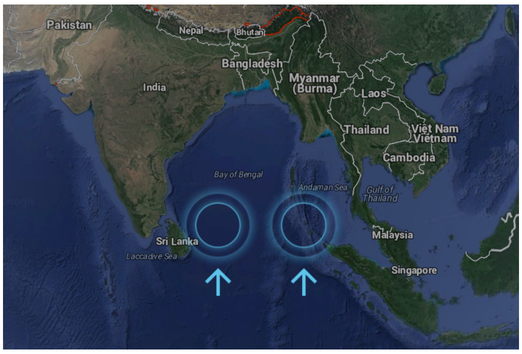
Befehl	**Art und Weise der Interaktion**
Navigieren	Die Karte mit dem Finger herumschieben.
Zoomen	2 Finger von einander weg / einander entgegen schieben.  oder per Doppelklick mit einem Finger um herein zu zoomen.
Drehen	Mit einem Finger um einen anderen Finger drehen. 
Neigen	2 Finger parallel voneinander nach oben / unten schieben. 

Figure 12. Interaction manual for those participants interacting with the multi-touch tablet.

Bedienung von Google Earth

Ihnen stehen mehrere Möglichkeiten offen, wie Sie mit Google Earth interagieren können.

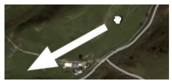
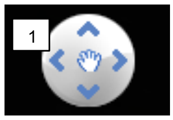
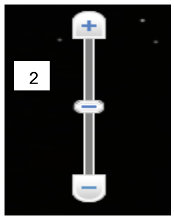
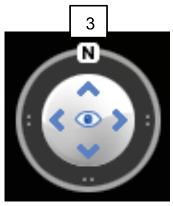
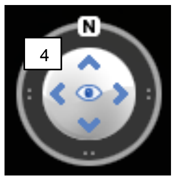
Befehl	Art und Weise der Interaktion	
Navigieren	a. Die Karte durch drücken der linken Maustaste herumschieben. b. Die Karte mit den Pfeiltasten der Tastatur oder den Tasten W, A, S und D bewegen. c. Auf der Karte mit dem Navigationselement (1) navigieren.	 
Zoomen	a. Durch Scrollen des Mausrades. b. Während dem Drücken der Pfeiltasten (oben/unten) die ⇧ shift- **und** die cmd ⌘ cmd-Taste gedrückt halten. c. Anhand des Zoomelementes mit dem +/- Symbol oder dessen Schiebebalken (2).	
Drehen	a. Während dem Scrollen des Mausrades die cmd ⌘ cmd-Taste gedrückt halten. b. Während dem drücken der Pfeiltasten der Tastatur (links/rechts) die cmd ⌘ cmd- **oder** die ⇧ shift- Taste gedrückt halten. c. Die Nordausrichtung der Karte mit dem Navigations-element (3) verändern.	
Neigen	a. Während dem Scrollen des Mausrades die ⇧ shift-Taste gedrückt halten. b. Während dem Drücken der Pfeiltasten (oben/unten) die ⇧ shift- Taste gedrückt halten. c. Mit dem Navigationselement in die gewünschte Richtung „sehen“ (4).	

Figure 13. Interaction manual for those participants interacting with mouse and keyboard on the desktop computer.

Übung Bedienung Google Earth

Sie haben nun die Möglichkeit das Interagieren (drehen, navigieren, zoomen und neigen) mit Google Earth bis zu 5 Minuten lang zu üben. Dafür erhalten Sie auch eine Anleitung, die Sie verwenden können, falls Sie diese benötigen.

Ich bitte Sie beim Üben „laut zu denken", d.h. alles was Ihnen gerade durch den Kopf geht mir mitzuteilen. Dabei kann ich sehen, ob Sie das Interagieren mit Google Earth verstehen oder noch zusätzliche Hilfe benötigen.

Wenn Sie sich in der Interaktion genug sicher fühlen, dürfen Sie mir dies jederzeit mitteilen. Sie können dann die thematische Einführung lesen und damit beginnen die vorbereiteten Aufgaben der Studie zu lösen.

Übungsaufgabe:
Sie möchten im Sommer die Nordinsel von Neuseeland bereisen.
Versuchen Sie:

a) die **Interaktion mit Google Earth zu üben** indem Sie die Nordinsel erkunden (navigieren, drehen, zoomen und neigen)
b) mehr Informationen zum See und Fluss herauszufinden indem Sie **mit den farbigen Symbolen interagieren (auf die Symbole kicken)**.

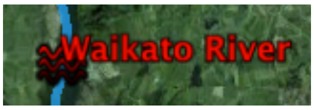
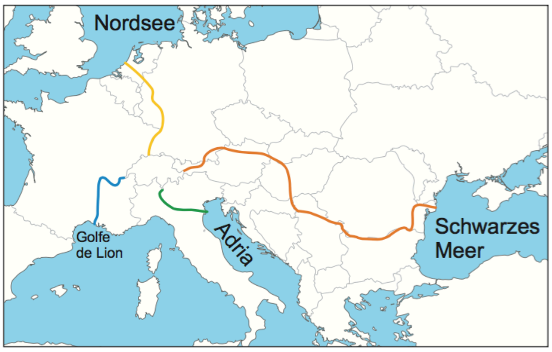


Figure 14. Instructions for practicing the interaction with the assigned device on Google Earth.

Das Wasserschloss Europas

Weil die Quellen der wichtigsten europäischen Ströme in den Schweizer Alpen liegen, gilt die Schweiz auch als das **Wasserschloss Europas**. Im Gebiet der Alpen entspringen viele Bäche und Flüsse. Das Wasser, das von Regen, Schnee und den Gletschern stammt, fliesst in verschiedene Richtungen:



Das Wasser aus dem Rhein (Gelb) fliesst in die Nordsee, die Rhone (Blau) in den Golf de Lion (westliches Mittelmeer), der Tessin über den Po (Grün) in die Adria (Mittelmeer) und der Inn fliesst über die Donau (Orange) ins Schwarze Meer.

Die Wasserscheide der Schweiz

Die Grenzen zwischen den Abflussgebieten in der Schweiz nennt man **Wasserscheide** (gepunktete Linien). In dieser Studie werden Sie mit Google Earth das gelb eingefärbte und grösste Abflussgebiet kennenlernen.
Sie werden **die Flüsse** und **Seen,** sowie deren Eigenschaften und Beziehungen zueinander lernen. Sie lernen in welchen Flüssen das Wasser durch **die grösseren Städte** fliesst, wo diese Flüsse entstehen, welche Seen sie speisen und wo sie mit welchen anderen Flüssen zusammenfliessen.
Nach der Interaktion mit Google Earth werden Sie über die wichtigsten gelernten Inhalte - Städte, Flüsse und Seen - und deren wichtigsten Eigenheiten abgefragt. Es ist also Ihr Ziel sich **Wissen über die Schweizer Flüsse und Seen anzueignen**. Ihre Lernziele sehen Sie dann auch auf dem jeweiligen Aufgabenblatt.

Je besser Sie im nachträglichen Test abschneiden, desto höher ist Ihre Chance zusätzlich einen Gutschein mit 50.- Wahrenwert zu gewinnen!

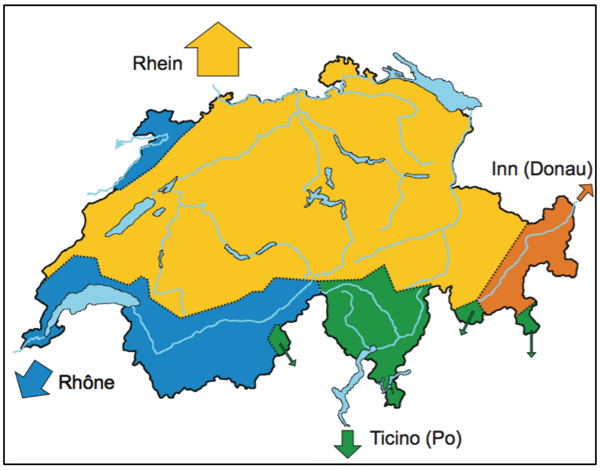


Figure 15. Thematic introduction sheet in which the participants read about the water that flows from different country areas out of Switzerland in different directions.

Task Sheets

Folgen Sie der Reuss von dessen Ursprung aus. Merken Sie sich dabei die Seen und die grösseren Städte. Versuchen Sie während dem Interagieren „laut zu denken“. Dies kann beim lernen geografischer Inhalte unterstützend wirken.

Aufgaben zum bearbeiten:

1. Welche zwei kleineren Flüsse vereinen sich zur Reuss?
2. Wo entsteht die Reuss?
3. Durch welchen See fliesst das Wasser der Reuss?
4. Aus welchem Fluss einexs Sees gelangt noch mehr Wasser in die Reuss?
5. Bei welchen grösseren Städten fliesst die Reuss in welchen grösseren Fluss?

Lernziele: - die Seen und Flüsse kennen.
- die wichtigsten Eigenschaften der Seen und der Flüsse kennen.
- die grösseren Städte am Fluss und an den Seen kennen.

Zeit für die Aufgaben: **6 Minuten**

Folgen Sie der Linth von dessen Ursprung aus. Merken Sie sich dabei die Seen und die grösseren Städte. Versuchen Sie während dem Interagieren „laut zu denken“. Dies kann beim lernen geografischer Inhalte unterstützend wirken.

Aufgaben zum bearbeiten:

1. Von welchem Bergmassiv stammt das Wasser der Linth?
2. In welche Seen fliesst das Wasser der Linth?
3. Wie heisst der Fluss, der nach dem zweiten See entsteht und in welchen anderen Fluss fliesst dieser?

Lernziele: - die Seen und Flüsse kennen.
- die wichtigsten Eigenschaften der Seen und der Flüsse kennen.
- die grösseren Städte am Fluss und an den Seen kennen.

Zeit für die Aufgaben: **5 Minuten**

Figure 16. The task sheet of the Reuss and the Linth that the participants used when learning with Google Earth.

Folgen Sie der Aare von dessen Ursprung aus. Merken Sie sich dabei die Seen und die grösseren Städte. Versuchen Sie während dem Interagieren „laut zu denken". Dies kann beim lernen geografischer Inhalte unterstützend wirken.

Aufgaben zum bearbeiten:

1. Starten Sie beim Ursprung der Aare und finden Sie heraus, aus welchen Gletscher ein Teil des Wassers der Aare stammt.
2. Welche Seen werden vom Wasser der Aare gespiesen?
3. Welcher Fluss fliesst am linken Ufer in die Aare?
4. Welche Seen sind Stausee?
5. Welche Seen dienen als Ausgleichsbecken bei Hochwasser?
6. Welche Flüsse fliessen am rechten Ufer in die Aare?
7. Wo mündet die Aare schlussendlich in einen anderen Fluss?

Lernziele: - die Seen und Flüsse kennen.
- die wichtigsten Eigenschaften der Seen und der Flüsse kennen.
- die grösseren Städte am Fluss und an den Seen kennen.

Zeit für die Aufgaben: **10 Minuten**

Folgen Sie dem Rhein von dessen Ursprung aus. Merken Sie sich dabei die Seen und die grösseren Städte. Versuchen Sie während dem Interagieren „laut zu denken". Dies kann beim lernen geografischer Inhalte unterstützend wirken.

Aufgaben zum bearbeiten:

1. Welche zwei kleineren Flüsse vereinen sich zum Rhein?
2. Wo entsteht der Rhein?
3. An welche Länder grenzt der Rhein?
4. Durch welchen See fliesst das Wasser des Rheines?
5. Welcher Fluss fliesst auch durch die Ostschweiz und dann in den Rhein?
6. Wo fliesst das Wasser aus anderen Flüssen der Schweiz in den Rhein?
7. Wo verlässt das Wasser des Rheines schlussendlich die Schweiz?

Lernziele: - die Seen und Flüsse kennen.
- die wichtigsten Eigenschaften der Seen und der Flüsse kennen.
- die grösseren Städte am Fluss und an den Seen kennen.

Zeit für die Aufgaben: **7 Minuten**

Figure 17. The task sheet of the Aare and the Rhine that the participants used when learning with Google Earth.

Questionnaires

Wie sehr stimmen Sie den folgenden Aussagen zu?

Ich weiss genau, wie ich auf der Karte **navigieren** werde,

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

nämlich:

Ich weiss genau, wie ich die Karte **drehen** werde,

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

nämlich:

Ich weiss genau, wie ich die Karte **zoomen** werde,

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

nämlich:

Ich weiss genau, wie ich die Karte **neigen** werde,

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

nämlich:

Bitte schätzen Sie Ihr **geografisches Wissen** auf der Skala von 1-7 ein.

O	O	O	O	O	O	O
1	**2**	**3**	**4**	**5**	**6**	**7**
Kein Wissen						Geografie Experte

Figure 18. Expectation about how to interact with Google Earth on the assigned device and asking about participants' estimated knowledge in geography.

Machen Sie in jeder Skala dort ein Kreuz, wo Ihrer Meinung nach **die Interaktion mit Google Earth** am besten verdeutlicht wird.

1. **Geistige Anforderung**:
   Wie viel geistige Anforderung war bezüglich dem Interagieren mit Google Earth erforderlich? (z.B. Denken, Entscheiden, Erinnern, Hinsehen, Suchen,...)

   O O O O O O O O O O O O O O O O O O O O
   gering **hoch**

2. **Körperliche Anforderung**:
   Wie viel körperliche Aktivität war beim Interagieren mit Google Earth erforderlich?
   (z.B. ziehen, drücken, drehen, steuern, aktivieren ...)

   O O O O O O O O O O O O O O O O O O O O
   gering **hoch**

3. **Zeitliche Anforderung**:
   Wie viel Zeitdruck empfanden Sie beim Interagieren mit Google Earth um die gestellten Aufgaben bearbeiten zu können?

   O O O O O O O O O O O O O O O O O O O O
   gering **hoch**

4. **Leistung**:
   Wie erfolgreich haben Sie Ihrer Meinung nach beim Interagieren mit Google Earth die vom Versuchsleiter gesetzten Aufgaben bearbeitet?

   O O O O O O O O O O O O O O O O O O O O
   schlecht **gut**

5. **Anstrengung**:
   Wie anstrengend war das Interagieren mit Google Earth, um Ihren Grad an Aufgabenerfüllung zu erreichen?

   O O O O O O O O O O O O O O O O O O O O
   gering **hoch**

6. **Frustration**:
   Wie unsicher, entmutigt, irritiert, gestresst und verärgert fühlten Sie sich beim Interagieren mit Google Earth?

   O O O O O O O O O O O O O O O O O O O O
   gering **hoch**

Figure 19. The translated and adapted NASA-TLX questionnaire to assess the perceived cognitive workload.

Bitte vergegenwärtigen Sie sich jetzt noch ein Mal die **Interaktion (zoomen, navigieren, drehen, neigen) mit Google Earth** und beschreiben Sie Ihr Erleben der Interaktion mit Hilfe der folgenden Aussagenpaare. Die Paare stellen jeweils extreme Gegensätze dar, zwischen denen eine Abstufung möglich ist.
Vielleicht passen einige Aussagen nicht so gut, kreuzen Sie aber trotzdem bitte immer an, welcher Begriff Ihrer Meinung nach eher zutrifft. Denken Sie daran, dass es keine "richtigen" oder "falschen" Antworten gibt - nur Ihre persönliche Meinung zählt!

Bei der Nutzung von Google Earth	1	2	3	4	5	6	7	
handelte ich überlegt	☐	☐	☐	☐	☐	☐	☐	handelte ich spontan
erreichte ich mein Ziel nur mit Anstrengung	☐	☐	☐	☐	☐	☐	☐	erreichte ich mein Ziel mit Leichtigkeit
handelte ich unbewusst, ohne lange über die einzelnen Schritte nachzudenken	☐	☐	☐	☐	☐	☐	☐	führte ich bewusst einen Schritt nach dem anderen aus
liess ich mich von meinem Verstand leiten	☐	☐	☐	☐	☐	☐	☐	liess ich mich von meinem Gefühl leiten
war ich orientierungslos	☐	☐	☐	☐	☐	☐	☐	konnte ich mich gut zurechtfinden
handelte ich ohne dabei nachzudenken	☐	☐	☐	☐	☐	☐	☐	konnte ich jeden Schritt genau begründen
Die Nutzung von Google Earth								
erforderte viel Aufmerksamkeit	☐	☐	☐	☐	☐	☐	☐	ging wie von selbst
war begeisternd	☐	☐	☐	☐	☐	☐	☐	war unbedeutend
war einfach	☐	☐	☐	☐	☐	☐	☐	war schwierig
war nichts Besonderes	☐	☐	☐	☐	☐	☐	☐	war ein magisches Erlebnis
war sehr intuitiv	☐	☐	☐	☐	☐	☐	☐	war gar nicht intuitiv
war belanglos	☐	☐	☐	☐	☐	☐	☐	war mitreissend
fiel mir leicht	☐	☐	☐	☐	☐	☐	☐	fiel mir schwer
war faszinierend	☐	☐	☐	☐	☐	☐	☐	war trist
Im Nachhinein ...								
fällt es mir schwer, die einzelnen Bedienschritte zu beschreiben	☐	☐	☐	☐	☐	☐	☐	ist es für mich kein Problem, die einzelnen Bedienschritte zu beschreiben
kann ich mich gut an die Bedienung von Google Earth erinnern	☐	☐	☐	☐	☐	☐	☐	fällt es mir schwer, mich zu erinnern, wie Google Earth bedient wird
kann ich nicht sagen, auf welche Art und Weise ich Google Earth bedient habe	☐	☐	☐	☐	☐	☐	☐	kann ich genau sagen, auf welche Art und Weise ich Google Earth bedient habe

Figure 20. The applied INTUI questionnaire to assess the perceived intuitive use of Google Earth.

Im Folgenden beurteilen Sie bitte wie es Ihnen bei der Interaktion mit Google Earth gegangen ist.

Die Interaktion mit Google Earth hat mir Spass gemacht.

Stimmt gar nicht	Stimmt wenig	Stimmt teils-teils	Stimmt ziemlich	Stimmt völlig
O	O	O	O	O

Ich fand die Interaktion mit Google Earth sehr interessant.

Stimmt gar nicht	Stimmt wenig	Stimmt teils-teils	Stimmt ziemlich	Stimmt völlig
O	O	O	O	O

Die Interaktion mit Google Earth war unterhaltsam.

Stimmt gar nicht	Stimmt wenig	Stimmt teils-teils	Stimmt ziemlich	Stimmt völlig
O	O	O	O	O

Mit meiner Leistung bei der Interaktion mit Google Earth bin ich zu frieden.

Stimmt gar nicht	Stimmt wenig	Stimmt teils-teils	Stimmt ziemlich	Stimmt völlig
O	O	O	O	O

Bei der Interaktion mit Google Earth stellte ich mich geschickt an.

Stimmt gar nicht	Stimmt wenig	Stimmt teils-teils	Stimmt ziemlich	Stimmt völlig
O	O	O	O	O

Ich glaube, ich war bei der Interaktion mit Google Earth ziemlich gut.

Stimmt gar nicht	Stimmt wenig	Stimmt teils-teils	Stimmt ziemlich	Stimmt völlig
O	O	O	O	O

Figure 21. Two applied dimensions of intrinsic motivation. The first three items assess interest and enjoyment and the second three items assess perceived competence.

Wahrgenommene Direktheit der Manipulation

Im folgenden geht es um die Beurteilung dreier Komponenten, welche bei der Interaktion mit Google Earth mitbeteiligt waren: Motorik, Wahrnehmung und Kognition - und dessen Beziehungen untereinander.
Erinnern Sie sich kurz daran, **WIE** Sie mit der Benutzeroberfläche interagiert haben. Denken Sie an Ihre Bewegungen, resp. die Befehle, die Sie dem System gegeben haben um navigieren, zoomen, drehen und neigen zu können.

Die Bewegungen der Karte konnte ich ohne Verzögerung oder Unterbrechung beobachten.

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

Es war schwierig zu merken wie ich die Karte verändern konnte.

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

Für mich war es körperlich anstrengend die Karte so zu verändern, wie ich es wollte.

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

Die Art und Weise, wie ich mit der Karte interagieren konnte, hat mit meiner Erwartung übereingestimmt, was dabei passieren sollte.

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

Ich hatte stets die Kontrolle darüber, dass sich die Karte genau so verändert hat, wie ich es wollte.

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

Die Art und Weise, wie ich mit der Karte interagieren konnte, hat mit dem was auf dem Bildschirm passierte übereingestimmt.

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

Figure 22. Perceived direct manipulation questionnaire.

Demografische Angaben

Bitte schätzen Sie Ihr **geografisches Wissen** auf der Skala von 1-7 ein

O	O	O	O	O	O	O
1	**2**	**3**	**4**	**5**	**6**	**7**
Kein Wissen						Geografie Experte

In welchen Situationen kommen Sie mit **Landeskarten** und der Schweizer Geografie in Kontakt? Haben Sie Hobbies, bei welchen Sie Karten brauchen?

____

____

____

Wo sind Sie **aufgewachsen**?

____

Wo in der Schweiz und **wie lange** haben Sie an diesen Orten **gelebt**?

In ________________ für ________

In ________________ für ________

In ________________ für ________

In ________________ für ________

Geschlecht

O Männlich O Weiblich O möchte ich nicht angeben

Alter in Jahren: Ich bin _____ Jahre alt.

Beruf / Studium: Welches ist / sind Ihre **aktuelle Beschäftigung/en**:

- O Studium: ________________________
- O berufliche Tätigkeit: ____________________

Ausbildung: Welches ist / sind Ihre bisherigen abgeschlossenen Ausbildungen?

____

____

Figure 23. Demographic questions about age, gender, education and places where participants grew up and have lived in, hobbies and situations in which they came in contact with maps.

Bitte schätzen Sie Ihr **geografisches Wissen** auf der Skala von 1-7 ein

O	O	O	O	O	O	O
1	**2**	**3**	**4**	**5**	**6**	**7**
Kein Wissen						Geografie Experte

Haben Sie seit dem ersten Termin **geografische Inhalte** der Studie **nachgesehen**?

0 Nein 0 Ja

Wenn ja, dann beschreiben Sie bitte kurz wie oft und wie lange Sie dies getan haben.

____

____

Mit welchem Gerät haben Sie dies getan?

0 Laptop 0 Tablet 0 Smartphone 0 Landeskarte

0 anderes: ______________________________

Mit welcher Applikation haben Sie dies getan?

0 Google Maps 0 Google Earth 0 maps.search.ch

0 andere: ______________________________

Figure 24. Participants estimated their geographical knowledge in the delayed post-test session. They further had to state whether they interacted with some of the learning content since the first meeting and if so, how often and on which device they refreshed their knowledge.

Wie sehr stimmen Sie den folgenden Aussagen zu?

Ich weiss noch genau, wie ich auf der Karte **navigieren** konnte,

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

nämlich:

____

____

Ich weiss noch genau, wie ich die Karte **drehen** konnte,

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

nämlich:

____

____

Ich weiss noch genau, wie ich die Karte **zoomen** konnte,

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

nämlich:

____

____

Ich weiss noch genau, wie ich die Karte **neigen** konnte,

Stimme überhaupt **nicht** zu	Stimme **nicht** zu	Stimme eher **nicht** zu	Stimme eher zu	Stimme zu	Stimme voll und ganz zu
O	O	O	O	O	O

nämlich:

____

____

Figure 25. Recall about how participants could interact with Google Earth on the first meeting.

Appendix B

Tables

Table 4

Differences Between Multi-Touch Tablet- and Desktop Computer Interaction

	Multi-Touch Tablet	Desktop Computer
Pinching	Directly pinching on symbols with any finger.	Moving the mouse until the cursor on the screen is over the symbol and then, clicking with the pointing finger on the left mouse button.
Navigating	Laying one finger on the screen to push the map away to see another part of the map.	Click and hold with the pointing finger on the left mouse button and moving the mouse around. Moving the map by pressing the arrow keys or the W, A, S and D key on the keyboard. Using the little arrows on the element button on the top right in Google Earth on the screen.
Zooming	Zooming in by double tabbing with a finger on the screen or moving two fingers on the screen apart from / towards each other for zooming in and out.	Double clicking with the pointing finger on the left mouse button where the cursor is to zoom in there automatically. Using the wheel on the mouse to zoom in (wheel foreword) and out (wheel backwards). Using the plus and minus element buttons on the top right in Google Earth on the screen. Click and hold the alternate mouse button and moving the mouse upwards / downwards to zoom in and out. Press and hold the cmd- and shift key and pressing the key up and down to zoom in and out.
Rotating	Rotating two fingers anti-/ clockwise or moving one finger around another on the screen.	Using the wheel on the mouse for rotating clock- (wheel foreword) and anticlockwise (wheel backwards) while holding the cmd-key. Using the visual element buttons on the top right in Google Earth on the screen to change the north orientation. Click and hold the alternate mouse button and moving the mouse left and right for rotating the map clock- and anticlockwise. Press and hold the cmd-key and pressing the key left and right for rotating the map clock- and anticlockwise.
Tilting	Moving two fingers parallel to each other down and upwards on the screen.	Tilt the view by pressing the shift-key and scrolling up to tilt the earth for horizon view, or scrolling down to tilt the earth back to top down view. Using the visual element buttons on the top right in Google Earth on the screen by clicking several times with the left mouse button on the visible arrow keys. Press and hold the shift-key and pressing the key up and down to tilt the earth for horizon view or back to top down view.

Note. These differences were gathered by the author.

Table 5

Means and Standard Deviations of Enjoyment and Feeling of Competence

	Enjoyment		Competence	
	Immediate Post-Test (*n* = 18)	Delayed Post-Test (*n* = 17)	Immediate Post-Test (*n* = 17)	Delayed Post-Test (*n* = 15)
Interaction Device	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Multi-Touch Tablet	4.07 (0.78)	3.90 (0.69)	3.78 (0.82)	3.61 (0.76)
Desktop Computer	3.73 (0.73)	3.71 (0.47)	3.71 (0.82)	3.78 (0.53)

Note. Scale ranges from 1 to 5.

Table 6

Means and Standard Deviations of the Perceived Level of Direct Manipulation

		Perception	Cognition	Motoric Input	Motor Cognition	Sensory Cognition	Sensorimotor
Interaction Device	*n*	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Multi-Touch Tablet	18	5.22 (0.65)	1.56 (0.62)	1.33 (0.59)	5.22 (0.55)	4.83 (0.92)	5.06 (0.73)
Desktop Computer	17	4.88 (0.93)	1.65 (0.86)	1.47 (0.87)	5.12 (0.86)	4.71 (1.11)	5.12 (0.86)

Note. Scale ranged from 1 to 6.

Table 7

Mean Percentage Knowledge- and Learning Scores for both Experimental Groups

	Knowledge			Learning	
	Pre-Test	Immediate Post-Test	Delayed Post-Test	Short-Time	Long-Time
Interaction Device	*M*% (*SD; n*)	*M*% (*SD; n*)	*M*% (*SD; n*)	*M*% (*SD; n*)	*M*% (*SD; n*)
Multi-Touch Tablet	27.85 (20.89; 18)	52.62 (23.31; 18)	51.16 (21.67; 17)	24.77 (9.36; 18)	25.84 (9.89; 17)
Desktop Computer	21.31 (15.23; 17)	46.99 (22.18; 17)	48.38 (22.30; 15)	25.68 (12.77; 17)	26.67 (12.37; 15)

Note. Mean percentage scores in geographical knowledge, measured at three different times. Short- and long-time learning as mean percentage score differences. Only participants who attended all sessions were included in the long-time learning scores.

Table 8

Means and Standard Deviations of Gender Differences in Geographical Knowledge

	Objective Test Knowledge			Self-Rated Knowledge		Learning Score
	Pre-Test	Immediate Post-Test	Delayed Post-Test	After Immediate Post-Test	After Delayed Post-Test	Short-Time
Gender	*M*% (*SD; n*)	*M*% (*SD; n*)	*M*% (*SD; n*)	*M* (*SD; n*)	*M* (*SD; n*)	*M*% (*SD; n*)
Women	15.21 (12.16; 19)	41.06 (18.05; 19)	43.00 (18.97; 17)	2.78 (0.94; 18)	2.88 (0.78; 17)	25.85 (10.24; 19)
Men	35.90 (18.48; 16)	60.36 (23.50; 16)	57.63 (22.48; 15)	3.50 (0.97; 16)	3.47 (1.06; 15)	24.46 (12.11; 16)

Note. Mean percentage scores in objective geographical knowledge measured at three different times. Self rated general knowledge measured at two times and short-time learning scores for woman and men.

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Non-plagiarism statement

I hereby declare that this thesis is my own work and that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Thomas Michael Keller

Basel, October 12, 2015