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Enhancing Knowledge, Skills, and Spatial Reasoning through Location-based Mobile Learning

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Abstract

Location-based mobile learning (LBML) involves learning in and about locations in order to explore, analyze, describe, and evaluate phenomena in authentic learning experiences and incorporate them into the real world. Learners gain an understanding of both the immediate environment using all the senses and the spatial perception to create a holistic impression of the environmental phenomena. Mobile mapping technologies and location-based services are utilized to link learning contents to specific locations as stories, tasks, or assignments. A large number of research projects on mobile learning have investigated LBML systems and LBML approaches with regard to learner satisfaction, usability and efficiency. The projects achieved predominantly positive results regarding motivation and engagement but only fragmented results regarding the cognitive learning outcomes.

This dissertation describes how an LBML system utilizing GIS technology enhances the educational learning outcomes with a special focus on the spatial thinking process. Furthermore, this dissertation describes novel approaches of visual analytics with 2D and 3D map web components to produce new teaching strategies during the activities and new metacognitive strategies to evaluate and reflect the activity.

The study presented in this dissertation covers case studies in universities, vocational schools, and informal education environments using design-based research to develop a mobile-friendly interactive mapping platform. Furthermore, the platform includes multimedia capabilities and interfaces to connect external services and content. The main study was conducted in a secondary school under real conditions and evaluated the technology regarding the learning performance and the teaching activities before, during, and after the activity.

The results reveal a better cognitive learning outcome in classroom exams when a teaching sequence of several weeks includes an outdoor activity of a double lesson. Moreover, there is potential for enhancing learning beyond the outdoor part to improve spatial reasoning. Long-term self-assessment of the learners, however, resulted in no impact, whether cognitively or affectively. The workload for outdoor teaching compared to classroom teaching is higher mainly due to the profound inspections of the location. The findings and their implications for research and teacher education were discussed in order to corroborate the educational value of LBML to motivate educators using LBML strategies for teaching.

Zusammenfassung

Ortsbezogenes mobiles Lernen (OML) beinhaltet das Lernen an und über Orte, um Umweltphänomene in authentischer Lernumgebung zu erforschen, zu analysieren, zu beschreiben und zu bewerten und sie in die reale Welt zu integrieren. Mittels sinnlicher und räumlicher Wahrnehmung erhalten Lernende einen ganzheitlichen Eindruck von der unmittelbaren Umgebung. Mobile Kartentechnologien und ortsbezogene Dienste werden eingesetzt, um die Phänomene mit Geschichten, Aufgaben oder Aufträge zu verknüpfen. In einer Vielzahl von Forschungsprojekten zum mobilen Lernen wurden LBML-Systeme und LBML-Ansätze hinsichtlich der Zufriedenheit, Benutzerfreundlichkeit und Effizienz der Lernenden untersucht. Die Projekte erzielten überwiegend positive Ergebnisse hinsichtlich Motivation und Engagement der Lernenden, aber nur uneindeutige Ergebnisse hinsichtlich der kognitiven Lernergebnisse.

Diese Dissertation beschreibt, wie ein OML-System unter Verwendung von GIS-Technologie die schulischen Lernergebnisse verbessern kann, wobei ein besonderer Schwerpunkt auf dem räumlichen Denkprozess liegt. Darüber hinaus beschreibt diese Dissertation neue Ansätze der visuellen Analytik mit 2D- und 3D-Karten-Webkomponenten, um neue Lehrstrategien für OML-Aktivitäten und neue metakognitive Strategien in der Nachbesprechung von OML-Aktivitäten zu erzeugen.

Die mobile interaktive Kartenplattform wurde mittels designbasierter Forschung in Zusammenarbeit mit Universitäten, Berufsschulen und informellen Bildungsumgebungen entwickelt. Die Lernplattform umfasst multimediale Funktionen und Schnittstellen zur Verbindung externer Dienste. Die Hauptstudie wurde in einer Sekundarschule unter realen Bedingungen durchgeführt und evaluierte OML im Hinblick auf die Lernleistung mit einer Abschlussprüfung im Klassenzimmer zur Unterrichtssequenz sowie einer Beurteilung der Lernleistung durch die Schülerinnen und Schüler selbst vor, während und nach der Aktivität.

Die Ergebnisse der Prüfung zeigt, dass ein besseres Ergebnis erzielt wird, wenn eine Unterrichtssequenz von mehreren Wochen mit einer OML-Aktivität ergänzt wird. Die Studie zeigt zudem, das Potenzial verschiedener Lerneffekte des OML über den OML-Teil hinaus, insbesondere des räumlichen Denkens. Eine langfristige Beobachtung der Selbsteinschätzung der Lernenden ergab jedoch keine Auswirkungen, weder kognitiv noch affektiv. Die Untersuchung der Unterrichtsplanung ergab, dass der Arbeitsaufwand für den OML-Unterricht im Vergleich zum Unterricht im Klassenzimmer höher ist vor allem aufgrund der umfassenden Rekognostierung vor Ort. Die Ergebnisse und ihre Implikationen für die Forschung und die Lehrerausbildung wurden diskutiert, um den pädagogischen Wert des LBML zu bekräftigen und Pädagogen, die LBML-Strategien für den Unterricht einsetzen, zu motivieren.

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List of Abbreviations and Acronyms

2D	Two Dimensional
3D	Three-Dimensional
A-GPS	Assisted GPS
AR	Augmented Reality
API	Application Programming Interfaces
CAI	Computer-Assisted Instruction
CBT	Computer-based Training
CC	Core Curricula
CGI	Cell Global Identity
CSS	Cascading Style Sheets
DBR	Designed-based Research
EDM	Educational Data Mining
EDK	Conference of Cantonal Ministers of Education
GIS	Geographic Information System
GUI	Graphical User Interface
HCI	Human-Computer Interaction
HMD	Head-Mounted Display
HTML	Hypertext Markup Language
HTTPS	Hypertext Transfer Protocol Secure
ICT	Information and Communication Technology
JS	Javascript
LA	Learning Analytics
LBMG	Location-based mobile Learning Games
LBML	Location-based mobile Learning
LMS	Learning Management System
MMLA	Multimodal Learning Analytics
MR	Mixed Reality
OMLETH	Ortsbezogenes, mobiles Lernen an der ETH
OSM	OpenStreetMap
PLE	Personal Learning Environment
RFID	Radio-Frequency Identification
TEL	Technology-Enhanced Learning
VA	Visual Analytics
WAAS	Wide Area Augmentation System
WLAN	Wireless Local Area Network

> Tell me and I forget. Show me and I may remember. Involve me and I learn.
>
> Xun Kuang (312-230 BC)

1 Introduction

Learning is the acquisition of knowledge, skills, and attitudes of an individual's cognitive system. It involves memorization and information recall. It encompasses understanding, relating ideas and combining prior and new knowledge, together with independent, critical, and creative thinking. Learning involves the ability to transfer knowledge to new and different contexts. It is "a process that leads to change, which occurs as a result of experience and increases the potential for improved performance and future learning" (Ambrose et al. 2010, p.3). This process takes place in two stages. The declarative stage consciously interprets facts and experiences within working memory and transfers them to the procedural stage. The procedural stage collates these facts and anchors them in procedures that are stored in long-term memory (J. R. Anderson, 1982). The declarative stage distinguishes between semantic and episodic memory (Eraut, 2000). Semantic memory contains general knowledge learned from words, symbols, and abstractions and must be repeatedly rehearsed by rote or use of schemata to remember it. Peer teaching, categorizing information, storytelling are trigger examples of semantic memories. Episodic memory contains specific, personally experienced events. The knowledge is associated with a specific event such as places, times, emotions.

1.1 Motivation

Traditional education, which is still practiced today at all school levels, refers to the approach used in the post-World War II era, which focused on rote learning and memorization (Magoulas et al., 2009). To achieve the quality of education desired, the teacher instructs students and guides their cognitive activity by emphasizing declarative skills and knowledge in controlled learning spaces (rooms), controlled time slots, controlled pedagogical environments, and controlled curricula. During the post-war period, mental ability tests such as the Primary Mental Abilities Test created by Thurstone (1938) were used to describe the full range of learner abilities (Zimmerman, 2013). Once the students were classified, teachers were asked to optimally align the learning objectives, instructional activities, and assessments with the cognitive level of each group of students that they taught. The results of this alignment could be statistically analyzed by Cronbach's (1957) analytical framework. These instructional theories had the consequence that learners were viewed as playing primarily a reactive rather than a proactive role (Zimmerman, 2013). In other words, the students were not encouraged to initiate or substantially supplement experiences as a method of educating themselves, but rather to become passive recipients and listeners (McManus, 2001) who engaged only on demand and in ways that were result-oriented, not content-oriented. This type of learning leads to a receptive transfer of knowledge, often activating the short-term memory only, and forms a barrier to real knowledge transfer and elaboration (Sun & Scott, 2005).

In contrast, the cognitive development theory advanced by Bruner (1966) describes learning as an active process in which learners construct new concepts based upon their prior knowledge, their choice of information and interest, their construction of hypotheses, and their decision making. Bruner (1966) suggested that teachers should organize the curriculum in a spiral manner—starting with the enactive stage first—so that the learners continually build upon what they have already learned. When the situation allows learner-centered activities, such as problem-based activities, active learners become self-regulated to the extent that they are metacognitively, motivationally, and behaviorally involved in their own learning process (Zimmerman, 1986). Therefore, active learning involves learning by thinking, doing, and reflecting. Epitomizing the pedagogical value of active learning for making learning more sustainable, Xun Kuang (312-230 BC) said, “Tell me and I forget. Show me and I may remember. Involve me and I learn.”

1.1.1 Geospatial context of learning objectives

Connecting learners with real-world situations is an essential target of active learning that involves a variety of context parameters, such as location, individuality, time, activity, and (social) relations (Jong et al., 2007; Zimmermann et al., 2007), and leads to unique, individual achievements in skill and knowledge areas. In real-world situations, location often influences not only the learning objective itself but is a part of it to gain knowledge about the location through an immersive experience. Together, the learning objective, the place in which learning occurs, and the geospatial characteristics of the learning form a unique set. Goodchild & Li (2011) formalize this composition with a geographic emphasis as follows: the site is part of the event, and the situation is the surroundings of the event or process, shown through the example of gentrification (discussed next).

> Gentrification, a research field in Urban social geography, is a complex inner-city revaluation phenomenon of structural, social, and functional upgrading, especially of old building quarters. In the upgrading process, poor or low-income neighborhoods in urban districts evolve, over time, into middle-class spaces. The positive image conveyed by the modernized areas leads to an influx of more affluent residents and businesses, moving into the neighborhood, who bring money (that in turn is spent on renovations and other house improvements, and infrastructure) and cultural activities and the associated displacement processes among the urban population (Lees, Slater, & Wyly, 2013).

Gentrification is a field of research in human geography and is deeply rooted in social dynamics and economic trends. To understand its physical and social characteristics, the signs, effects, and trajectories are largely determined by the local context (Lees et al., 2013).

Learning subjects with geospatial contexts, such as gentrification, are best experienced holistically and authentically *in situ*, allowing learners to grasp the diversity and complexity of the problem. Through such multi-perspective experiences, learners benefit from both episodic and semantic memory, shaped by the hippocampus, which is a part of the human brain where spatial information is encoded (Duff et al., 2020). A geospatial understanding of the spatial configuration of real-world objects matters because it enables people to integrate different environmental landmarks (salient objects) into a cognitive map—a mental model of objects' spatial configurations (Newman et al., 2007). Mental maps allow navigation along the optimal paths between arbitrary pairs of locations and involve the ability to maintain human activities with infrastructural impacts (e.g., urban planning, transportation), the understanding of social-psychological theories (e.g., culture, economy, justice), or skills to master natural phenomena (e.g., scenic, ecological, climatological processes) (National Research Council, 2005).

Connecting learners with situations *in situ* can be enhanced through the use of mobile and context-aware technology to deliver information in the right form to the right place at the right time (Zimmermann et al., 2005), to assist navigation and spatial understanding with interactive maps (Arlinghaus et al., 2019), and to spatially arrange physical objects and devices with location-based services (H. Huang et al., 2018).

1.1.2 Location-based mobile learning

In the contemporary world, mobile phones are an integral part of people's lives and culture and have become indispensable in informal learning environments, where learners set their own learning goals and strategies (Shuler, 2009). Therefore, contemporary education, in which students recognize that they are developing specific skills that they find relevant to the world outside of school, means a shift toward learning activities that include mobile technology and learner-centered pedagogy. While the concept of "mobile learning" posits that learning is continuous, situated, authentic, context-aware, and personalized (J. E. Traxler & Wishart, 2011) anytime and everywhere (Shuler, 2009), the concept of "location-based learning" is narrowed down to learning in and about the context with a geospatial target in mind (E. Brown et al., 2010). Location-based learning with context-aware mobile phones makes geolearning—learning in and about location—possible by linking to digital content and by collecting and sharing content at the right place using multimedia (Sharples, 2019). The location reflects the learning object, or as McLuhan (1964) would probably say, the location is the message.

For the last 20 years, researchers in GEES disciplines (geography, earth, and environmental sciences) have developed applications for location-aware computing by combining Global Positioning Systems (GPS) and Geographic Information Systems (GIS) to share and collect digital content (Frank, Caduff, & Wuersch, 2004; Haller & Rhin, 2005; H. Huang et al., 2018; Tsou, 2004), which stimulate users' spatial skills. Demonstrating this fostering of spatial understanding, along with the exercise of spatial thinking, educators from Geography have, for example, used GPS and interactive maps on mobile devices (Kerski, 2015; Milson & Kerski, 2015; Niederhuber et al., 2014; Viehrig et al., 2019; Woodli, 2007). Research on location-based mobile learning (LBML) has been witnessed in development projects carried out in collaboration with biological and learning scientists. For instance, in the project called the Cornucopia and Plantations Pathfinder (Rieger & Gay, 1997), students needed to seek plants at specific locations, and they documented their learning processes through location-based note-taking. In the Ambient Wood project of Rogers et al. (2004), which contained an immersive treasure hunt, students were to experience the learning content within forested surroundings in a gamified way. The project CAERUS (Naismith et al., 2005) provided for location-based audio content to engage visitors in a botanic garden. The Environmental Detectives project (Klopfer & Squire, 2008) simulated a hazardous scenario, such as a toxic spill, for which students had to find the source by collecting samples using trial and error learning approaches.

The presented projects have demonstrated that teaching such content at a specific location, using mobile technologies, can improve the motivational, cognitive, and spatial cognitive aspects of the learning process. Through the process of *in situ* learning, learners gain a significantly better understanding of spatial relationships and the surrounding context and are enabled to significantly better relate their semantic knowledge to their own experience and imagination in episodic memory (Lude et al., 2013). Therefore, LBML research plus the trend toward increasing the use of mobile phones in schools have created a growing demand for the development of pedagogical approaches and new applications in formal learning environments (Tiitinen, 2015).

1.2 Problem statement and research questions

Over the past two decades, researchers have studied the benefits and appropriateness of using mobile phones as tools for supporting location-based mobile learning, and have evaluated through explorative studies how mobile phones work for this purpose if they are liked, and if their use enhances learning (Sharples, 2009). Literature reviews on mobile technologies (Naismith et al., 2004), on mobile inquiry-based learning (Suárez et al., 2018), on science learning (Zydney & Warner, 2016), on seamless learning (Wong & Looi, 2011), on mobile learning projects (Frohberg, Göth, & Schwabe, 2009), on mobile and ubiquitous learning in higher education (Pimme et al., 2016), on location-based games (Avouris & Yiannoutsou, 2012), and on location-based mobile teaching (Baran, 2014) have summarized hundreds of research studies that found mostly positive results regarding effectiveness and satisfaction. Also, these studies sometimes addressed usability, which was not found to be a particularly relevant factor, and which was counterbalanced by the novelty of the technology. With regard to cognitive learning outcomes, the empirical evidence on cognitive learning outcomes is fragmented and cannot be substantiated (Schwabe & Göth, 2005). Only few studies report comprehensible differences between learning with a mobile device and learning with more traditional teaching (e.g. regular classroom lessons) (Schmitz, Klemke, & Specht, 2012).

Today, although mobile devices are increasingly used in schools, LBML does not yet have an impact on education as established pedagogy unlike learning with productivity tools or learning management systems in regular lessons. We have little idea why this is the case, and little evidence from exams in real school contexts about how students behave in LBML projects today, at a time when mobile communication media and productivity tools on tablets or laptops are naturally used for educational purposes. Moreover, we do not know how teaching with LMBL works under real circumstances and how learners proceed with the acquisition of skills and knowledge, nor how sustainable LBML is in real contexts with real examinations. Regarding the quantitative effect size, there is, for instance, no statistical estimate published for location-based mobile learning in the 800 meta-studies examined by Hattie (2013). There is a lack of evidence regarding the use of LBML in project-based settings in real contexts, where, for example, students can debrief and process the LBML activities based on recorded personal learning tracks such as documentation, visited locations, or personal movement as a journey. Aside from Baran's (2014) review about teaching, there are few field reports on the use of LBML in real contexts from the teacher's perspective. Reports are also lacking regarding experiences and guidelines about which concrete teaching requirements and demands on the LBML system are necessary to master the preparation, implementation, and debriefing of LBML lessons. Therefore, the main objectives of this dissertation focus on the applied field of LBML that can be captured by analyzing the learning process of teachers and students using the following main research questions (MRQ):

MRQ1. Technology:

What are the key features of an LBML system with advanced GIS that cover the entire LMBL teaching and learning process?

MRQ2: Teaching:

What are the key findings about teaching an LBML lesson for real-world contexts, and to what extent does LBML teaching differ from other teaching strategies such as classroom instruction, e- learning courses, or excursions without mobile technologies?

MRQ3: Learning processes and outcomes:

For lessons addressing real-world contexts, how do learning outcomes differ for classroom instruction with the intervention of an LBML lesson versus classroom instruction without an LBML lesson?

1.3 Contributions and scope

The contribution of this dissertation is manifold, and the scope of the study encompasses different research areas, including technology-enhanced teaching and learning, spatial cognitive science, and the educational science of the GEES disciplines. The development of the LBML system, through a research-based design approach in cooperation with secondary, tertiary, and vocational teachers and students, offers new perspectives for applied teaching and learning research and new insights for practicing educators, curriculum developers, and experts in educational technologies.

This dissertation provides new perspectives and insights by implementing a prototypical LBML system using the latest web GIS technologies and drawing on scholarly literature and case studies related to real environments of universities and schools. The LBML system enables the creation of multimedia content as point or area features on an interactive map interface using GIS tools that support the allocation of the content. Navigation and access to interactive learning content are regulated by location-based services, including positioning technologies such as GPS. Exploring learners gain access to the specific learning activity only at the physical location of the learning content. Furthermore, the LBML system collects the users' movement data during their discoveries and observations to monitor the process and safety issues via 2D and 3D map interfaces. This learning analytics framework provides instructors with new perspectives in teaching during the activity and for teachers and students after the activity as part of the debriefing phase.

Case studies from the perspective of the teacher (preparation, execution, reflection) and the students (execution, reflection) contribute by sharing best practices as well as solutions to problems that occurred. A large-scale empirical study of students at several schools provided insights into the teaching and learning processes of LBML. The teachers' experience reports yielded valuable insights into approaches, efforts, and effectiveness in the preparation, execution, and debriefing of LBML activities. These insights, in turn, contribute to understandings and the implementation of best practices in teaching LBML. The learning processes were examined by data analysis and self-assessment over three months after the activity. These findings provide insights into the cognitive, spatial-cognitive, and affective domains. The cognitive learning outcome of the activity was measured with a real examination. The insights gained from the numerous empirical studies provide a novel contribution to the field of LBML research and corroborate the educational value of LBML to motivate educators using LBML strategies for teaching. This dissertation relies on the following publications:

Chapter 3 Implementation of a location-based mobile learning platform

- Sailer, C., Kiefer, P., & Raubal, M. (2015). An Integrated Learning Management System for Location-Based Mobile Learning. *International Association for Development of the Information Society*.
- Schito, J., Sailer, C., & Kiefer, P. (2015). Bridging the gap between location-based games and teaching. In *AGILE 2015 Workshop on Geogames and Geoplay*. ETH Zürich.

Chapter 4 Evaluation of location-based mobile learning

- Sailer, C., Kiefer, P., Schito, J., & Raubal, M. (2015). An evaluation method for location-based mobile learning based on spatio-temporal analysis of learner trajectories. In *Proceedings of the 17th International conference on human-computer Interaction with mobile devices and services Adjunct*,1212-1218
- Sailer, C., Schito, J., Kiefer, P., & Raubal, M. (2015). Teachers matter: Challenges of using a location-based mobile learning platform. In *International Conference on Mobile and Contextual Learning*, 239-255. Springer, Cham
- Sailer, C., Kiefer, P., Schito, J., & Raubal, M. (2016). Map-based visual analytics of moving learners. *International Journal of Mobile Human Computer Interaction (IJMHCI)*, *8*(4), 1-28.

Chapter 5 Conclusion

- Sailer, C., Kiefer, P., & Raubal, M. (2018). OMLETH: A multimedia guide for field trips. *ETH Learning and Teaching Journal*, *1*(1).

Chapter 6 Future work

- Graf, A. B., Sailer, C., Jonietz, D., & Weibel, R. (2018). Towards Extracting Motivation from Mobile Learners' Movement Trajectories. In *Adjunct Proceedings of the 14th International Conference on Location Based Services*, 69-74. ETH Zurich.
- Sailer, C., Rudi, D., Kurzhals, K., & Raubal, M. (2019). Towards Seamless Mobile Learning with Mixed Reality on Head-Mounted Displays. In *World Conference on Mobile and Contextual Learning,* 69-76.
- Sailer, C., Martin, H., Gaia, L., & Raubal, M. (2019). Analyzing performance in Orienteering from movement trajectories and contextual information. In *15th International Conference on Location-Based Services*, 141-146.

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1.4 Dissertation overview

The structure of the dissertation is as follows: Chapter 2 provides a historical overview of computer technologies and their interaction with teaching and learning, as well as an analysis of how the acquisition of knowledge, skills, and attitudes has been viewed in different pedagogical epochs. A brief explanation of how the related work fits into the dissertation is listed at the end of each of the main sections. Chapter 3 illustrates the implementation of a location-based mobile learning platform, including its various user interfaces and the underlying pedagogical reasons for its design. Chapter 4 presents the preliminary studies, in which exploratory research was conducted in higher education, secondary schools, and informal learning environments. It details a novel approach to learning observation through map-based visual analysis of the learner's movement data. The chapter continues with an experimental study in geography at the secondary level, which mainly examines the differences seen in cognitive learning outcomes between (1) the combination of traditional classroom instruction and an LBML field trip intervention and (2) traditional classroom instruction without such an intervention. Chapter 5 summarizes the results and contributions of this dissertation. Chapter 6 gives an outlook on ongoing and future work.

[1] https://ethz.ch/en/the-eth-zurich/education/innovedum.html (01.01.2020)

2 Literature Review

Creativity and critical thinking are significant competencies for a human being to live in complex, globalized, and digital economies and societies (Vincent-Lancrin et al., 2019). Consciously and reflectively reinforcing and mobilizing knowledge, procedures, and attitudes are crucial to thriving in a rapidly changing world (Ramos & Schleicher, 2016). Ramos and Schleicher (2016) called being 'actionable' a clear behavioral goal that inseparably unites the ability to construct, transfer, and reflect knowledge, skills, values, and attitudes as competence.

Digital Communication as a cultural revolution

In the problem-solving learning process, creativity, critical thinking, collaboration, and communication are vital competencies (Ananiadou & Claro, 2009). Communication and human evolution evolve simultaneously, and with the introduction of orality and writing, a paradigm shift for business and society has occurred (Giesecke, 1995). For a paradigm shift of a key medium, a community usually needs several generations. The development is evolutionary in small steps, because change requires resources and knowledge growth (Ong, 2013). The current transformation of the key medium from analog to digital communication, on the other hand, is proceeding much faster than previous transformations and is therefore also referred to as the digital cultural revolution (Giesecke, 1995).

Learning is a complex process and has evolved differently in different cultural contexts (Neubert, Reich, & Voß, 2001). Contemporary education is affected by the educational paradigms of *behaviorism, cognitivism, constructivism, and connectivism*. These paradigms shape and *are* shaped by technologies (Sharples, Taylor, & Vavoula, 2005). With the emergence of the internet, a new standard - the digital age - has appeared, and it has disrupted existing conventions (Siemens, 2005). The connectivity and contextuality of mobile computers converge the pedagogies of formal and informal learning (Glahn, Börner, & Specht, 2010; Sharples et al., 2005) and create phenomena such as lifelong learning (Jong et al., 2007; Sedory Holzer & Kokemueller, 2007; Sharples et al., 2007).

The primary motivation of this dissertation is that connectivity and contextuality of mobile phones and tablets afford new opportunities for new learning spaces. Such devices feature learning content with direct reference to places in the real world. This enables learning about the specific, *in situ* environment (E. Brown et al., 2010), understood as geolearning and related to traditional field-based education, focusing on the natural elements of a location (Sharples, 2019).

Learning about the location

Field-based education activities have the goal of acquiring new knowledge or applying acquired knowledge to real problem situations (Neeb, 2010; von Niederhäusern et al., 2012). Beames et al., (2012) argue that outdoor learning brings instruction to life. The physical activity, including exploring and wayfinding in geographical space, stimulates spatial thinking and cognitive activity (National Research Council, 2005). Location-based inquiries support spatial reasoning.

In addition, the brain continuously collects and interprets information through the human senses, which in combination with the cognitive and spatial thought processes affects the possibility of information processing according to the Information Processing Theory (Miller, 1956) and Cognitive Load Theory (Sweller, 1994). Therefore, a system that combines location-based multimedia content with natural elements in situ, improves a person's primary sense (visual, auditory and tactile) with naturally invisible information (Specht, Ternier, & Greller, 2011), but according to the Multimedia Theory (Mayer, 2005), also uses additional brain power. Therefore, the learning content, however, must be carefully and consciously designed based on various pedagogical-psychological theories which will be presented in this chapter.

Structure of related work

This literature review presents the history of mobile learning and the use of computers and mobile devices in education. Section 2.1 discusses the influence of communication media on cultural change. This influence affects several learning paradigms that use computers, as will be discussed in the following chapters. Section 2.2 describes the stimulus-response computing for behavioral change. Section 2.3 reviews the computer-assisted instruction for knowledge acquisition. Section 2.4 presents the networked computing for knowledge construction, and Chapter 2.5 the location-aware computing for knowledge contextualization. Section 2.6 discusses the geospatial technologies for wayfinding assistance, spatial concept mapping, and spatial reasoning, and Section 2.7 concludes the literature review.

2.1 Communication media and cultural change

Culture is a human construct of social behavior, expectations, and values (Crompton 2013) that guides coexistence. Language is regarded as the ordering system of communication and has various media forms. These forms have personal and social consequences in the way we learn a language. McLuhan (1964) defined this process through the phrase, "*the medium is the message*." He suggested that a medium, not the content it holds, should be the focus of the investigation of communication.

The medium is the message, McLuhan 1964

Media are cultural techniques and convey language and action. Media influence all relevant areas of information and communication systems and create conditions for new social structures (Baecker, 2007; Niklas, 1984). According to Giesecke (1995), the cultural history of humanity - the history of education - can be described as media history. Social interaction is characterized by certain communication media, known as the **mainstream media.** The communication media was, therefore, integral for the social change and had, to some extent, shaped education (Sharples et al., 2007).

2.1.1 Analog mass literacy

Orality

The introduction of language established the tribal society (Baecker, 2007). The human voice was, in many respects, the principal medium that determined pre-literate society and culture - a fact that is evident in the example of the concept, structure, and transmission of knowledge. Knowledge only existed in human memory, and it was transmitted verbally as historical, social and religious information (Ong, 2013). Since there was no written storage, techniques were developed to structure and store knowledge in a way that could be memorized and retrieved orally. To recall knowledge, easily memorable images were created. These are known as mnemonics (Niegemann, 2008). The oral traditions were, therefore, stories with poem-like repetitions, keywords, or proverbs. Mnemonics are used today as strategies for extraordinary memory performance, and as simpler forms, such as situational element of elaboration (Karsten, 2011). Orality as a medium for storing and passing on knowledge, thus affects the structure and content of information (Niegemann, 2008).

Mnemonics as a cognitive strategy

Scriptography

The introduction of writing established ancient high culture in the fourth millennium B.C (Baecker, 2007) and solved the problem of the unavoidable distortion of meaning to oral mediation. The written form made it possible for people to exchange information in complex forms over a more extended period and decoupled from human mind as carrier (Ong, 2013).

Writing as an institutionally organized activity

In contrast to language, the acquisition of writing skills is not part of the natural development of human beings. Learning to write became an institutionally organized activity (Fichtner, 2008), which the ancient Greek philosopher Plato criticized. He claimed, that writing makes people forgetful and dependent on external resources and thus their minds were weakened (Ong, 2013). Others, conversely, argued that missing contexts and independence from spatial and temporal presence forced the writer to a more precise form of expression. This made it possible to present abstract concepts such as definitions (Fichtner, 2008).

Typography

The introduction of printing established modern society in the 15th century (Baecker, 2007). Invented by Johannes Gutenberg, printing made it possible to reproduce the written word quickly and precisely in large editions. Reading became popular, and the effects on the economy and society were manifold. People are better informed on the same piece of information, could re-read the written word, adapt the pace of acquiring the information as distinguished from the oral exchange, and are encouraged to reflect and further thinking. In this era of mass printing competence, the textbook was the primary medium of teaching, and a key goal was the active mediation of the science (Sharples et al., 2007). Book printing initiated democratization of the creation and dissemination of information in the form of knowledge, news, and opinions. The appearance of the printed book provoked a shift in consciousness (McLuhan et al., 2011). Following his axiom, "the medium is the message," McLuhan (1964) argued that technologies are not only inventions used by humans, but humans are reinvented through their use. In the beginning, the printing machine could print in black and white or text only, which was tedious for scientific researchers, who had to rely on exact and colorful illustrations. Due to the technical limitations of the printing press, the black-and-white book page developed with uniform page dimensions, often limited page numbers, as a template for the representation, standardization, and classification of knowledge (Baecker, 2007). The standardization of the printed book is still reflected today in most research publications, despite digital storage possibility (Blind et al., 2018).

2.1.2 Digitality as mass literacy

The introduction of the computer and the internet resulted in the information society (Baecker, 2007). Digital communication has its origins in the US Department of Defense. Motivated to overcome communication issues on account of vast geographical distances, the Department sought to utilize long-distance networking. It was through this pursuit that, in the 1960s, research commenced on ARPANET, the first packet-switched network using the TCP/IP protocol suite (Leiner et al., 2009). On October 29, 1969, Computer Science Professor Len

Kleinrock of the University of California, Los Angeles successfully transmitted the first message via ARPANET to a computer at the Stanford Research Institute near San Francisco. This moment marked the birth of the Internet (Byung-Keun, 2005; Leiner et al., 2009). As a result of TCP/IP, some pioneers communicated scientific results network-based with multimedia personal computers via local networks. Digital communication was limited by location-based storage in network infrastructures. Because analog exchange (face-to-face discussion) was often faster than that of computers, Tim Berners-Lee, a scientist from the Swiss and French CERN laboratories, in 1989 sought to solve this through the principle of hypertext[2]. He invented HTML (Hypertext Markup Language), the Hypertext Transfer Protocol (Http), the Internet Protocol address of the computer (IP), and the first web browser WorldWideWeb (WWW) – with its first website still in existence today (see website http://info.cern.ch/ (29.10.2019)).

Digitality as mainstream media in the digital age

The introduction of the Internet was a revolution. It radically changed how people communicated with each other and heralded new structures and processes to communicate and act (Baecker, 2007). Internet democratized knowledge and education by making knowledge accessible to all. The consequences for the traditional mainstream media and their consumers were striking. Digital mainstream media encountered new relationships with the audience (interactivity), new languages (multimedia), and a new grammar (hypertext) (Salaverría & Sádaba, 2003). According to Stalder (Stalder, 2016), the introduction of digitality had three social impacts: referentiality, community, and algorithmicity, as follows:

- The internet, as a mass communication system, enables a broad spectrum of new actors to participate in cultural processes. These actors create their social networks with new meaningful references. Consequently, **referentiality** has changed. Established structures, such as publishing houses, have lost their significance.
- Social media form a virtual **community**. This self-regulated order creates personal identity, trust, and yet often an information bias. People inform and enquire within the community, and unwanted information can disturb thinking and can be discarded.
- The **algorithmicity** of web-based search inquiries determines the properties and sequence according to which the selection was made. These criteria are usually not transparent. Through the process of evaluating the information, and the setting of the

[2] https://www.w3.org/People/Berners-Lee/Kids.html (28.11.2019)

stopping points in the search, the user controls himself/herself in a way that differs from their information-gathering in books.

Today, social media such as Facebook, LinkedIn, and Twitter (Crompton, 2013) are consequences of this development. Social media breaks through the classroom walls and enables students to work interactively and independently of the formal contexts in schools (Tiitinen, 2015). They allow users with mobile phones to exchange information and ideas interactively, in a way that provides feedback asynchronously in various forms, anytime and from anywhere (Bates, 2018). This change requires awareness and new communication skills (Bates, 2018; Honegger, 2016). The increasing flood of information, changing knowledge databases and more complex systems affect technology-enhanced learning, especially with mobile phones. Inquiry-based learning requires critical thinking and filter competences in search of information and self-regulated stopping points reading social media notifications (Ananiadou & Claro, 2009), especially for the generation smartphone (Siewiorek, 2012). Today's generation of students is growing up with information and communication technology (ICT) embedded in their daily lives. Today's generation of students is growing up with information and communication technology (ICT) embedded in their daily lives (Huizenga et al., 2009). In 2020, these students will be connected via mobile technologies, work interactively and socially, solve problems on the go, and are willing to complete several mobile tasks more or less simultaneously suggested Siewiorek in 2012.

2.1.3 Relevance to this dissertation

The previous sections described how developments in the field of communication have deeply affected the structure of human society and the culture of learning throughout history. Recent history shows an information and communication revolution. Two decades ago, landline telephones with synchronous oral two-way transmission and a limited internet were the primary means of communication between people. Today, billions of people use their smartphones to transmit multimedia content, synchronously and asynchronously, over broadband Internet connections. The world’s internet users soared from half a billion in 2000 to more than three billion in 2014. The number of mobile phone subscribers increased to more than six billion over the same period (Jorgenson & Vu, 2016). Social media and messaging application revolutions are widespread. They relate to research question **RQ1** regarding key features of a state-of-the-art LBML system, including the provision of communication tools or interfaces. If the system supports any messaging and social media application as a service, the question arises (and addresses research question **RQ2**) how teachers and lecturers who design LBML activities can make use of the range of possibilities for integrating and utilizing interaction and communication. The implemented designs and teaching approaches then influence how students interact and communicate during the learning process and how learning outcomes are affected by such designs (addressed in research question **RQ3**). The development and evaluation of the LBML system in Chapter 3 concerns all three research questions. Chapter 4 examines the effectiveness of LBML with an experimental study in which the communication design is also part of the analysis of teaching preparation and execution (**RQ2**) and the effects on the learning process (**RQ3**).

2.2 Behavioral change and stimulus-response computing

At the beginning of the 20th century, psychological theories about human thinking gained significant momentum. Psychoanalysts such as Freud (1955) developed far-reaching methods on the functioning of human thought, distinguishing between the conscious and subconscious. Such theories, however, were criticized and rejected by representatives of behaviorist learning theorists (see Watson (1913)). Behaviorism theorists believed that activities within the mind, in terms of inner psychological processes, were a black box, and that what occurred was purely speculative. Thus, they believed that observable behavioral changes should be investigated, as common at that time in the natural sciences (Ertmer & Newby, 2013).

2.2.1 Learning as stimulus-response behavior

Behavioral learning means a sustainable change in behavior based on fixed rules (Neubert et al., 2001). The acquired knowledge should be imparted in the learner utilizing stimulus-response learning through the repeated coupling of stimuli. Wrong answers result into a punishment, and correct answers are rewarded. In pedagogical terminology, learning as a change in behavior is understood as conditioning. There are three types of conditioning required to acquire competence (Woolfolk Hoy & Schönpflug, 2008):

Classical conditioning of Pavlov (signal learning)

The first conditioning is *classical conditioning*, whereby behaviors are triggered in ways that are dependent on stimuli. This approach was described in, and applied within the context of, the *Learning Reflex Theory, a theory* designed by Russian medical researcher Ivan P. Pavlov (Bouton, 2007). In 1905, Pavlov demonstrated that dogs have a congenital reflex (unconditioned reaction) that is triggered when food (uncoordinated stimulus) enters their mouth. Conversely, a ringing bell (neutral stimulus) showed no conditioned response in dogs, other than curiosity.

Operant conditioning of Thorndike (learning from consequences)

The second conditioning is the *operant conditioning* of the American behavioral scientist Edward L. Thorndike with different types of consequences as a function of reaction strength (Woodworth & Thorndike, 1901). Thorndike invented the operant conditioning during the turn of the 19th century, intending to improve military training with more efficient measuring methods (drill and practice) (Gormezano & Moore, 1966). Thorndike used cats to illustrate the principle of *learning through error and success* and *learning from consequences*. A cat was locked in a cage and observed to see if and when it would (accidentally) push the cage door lever to exit. The cat was then put back in the cage, and was observed again, to see if and how quickly it would (intentionally) push the exit lever. On the second attempt, it was observed that the cat pressed the lever and exited the cage more quickly. After several attempts, the cat pressed the lever immediately after being locked in the cage (Bouton, 2007).

Behavioral modification of Bandura (learning via imitation)

The third conditioning of behavioral acquisition of competence is described in Albert Bandura's (1988) *Social Learning Theory*. The acquisition takes place through observation and memorization of behavior patterns of other people. The success of the learner (observer) is measured by the performance of how well the model's (teacher's behavior) behavior pattern can be retrieved. Bandura aimed to establish how well linguistic patterns are acquired through models. Although the ability to imitate was decisive, Bandura believed that human behavior could not be explained by stimulus-response connections alone. Influenced by cognitive psychology, he assumed that the human cognitive system is partly responsible for the reaction.

Law of Learning

Pavlov and Thorndike identified several laws of learning, which is applicable to the learning process (Woolfolk Hoy & Schönpflug, 2008):

Extinction is observed if the classical or operant reaction of a stimulus gradually stops emerging. The learning process is deactivated. In classical conditioning, extinction occurs when the conditional stimulus is presented several times *without* the unconditional stimulus. For example, if a person threatens without action, others see an empty threat and adapt to it. In operant conditioning, extinction occurs when the behavioral consequence of the operant's enhanced behavior is *absent* more than once. Success increases the probability of occurrence due to its positive effects (learning by success). The error reduces unpleasant consequences and, therefore, the likelihood of occurrence. Thorndike generalized the realization in the form of two stimus-reaction principles that should occur in humans and animals:

Learning transfer

- **Law of exercise** (exercise -> success): The repetitive exercise reinforces the neuronal connection between the situation and response in the human head. The law is also known as the transfer of practice or *learning transfer*.
- **Law of effect** (stimulus -> satisfaction): Satisfactory results of the exercise are reinforced, and unpleasant consequences become weaker.

Extinction is not about forgetting, but about additional learning. This temporarily and context-dependently deactivates the effect of the conditional stimulus. A stimulus generalization occurs if similar stimuli trigger the same response. The more similar the new stimulus is to the conditioned stimulus, the stronger the reactions will be. The learning transfer is a result of generalization. The learned behavior must be transferable to situations with identical or similar characteristics. A successful transfer takes place, for example, in outdoor education of classifying trees. If learners learned to recognize and classify elms, they should be able to classify the maple trees according to the same procedure. The similarities between elm and maple tree enable the learner to apply the prior learning experience of the elm to the task of maple tree classification (Ertmer & Newby, 2013). Stimulus discrimination happens when the learner distinguishes between several stimuli. The conditioned reaction only occurs with exactly the stimuli of the learned context that were coupled with the response in the learning situation.

Behavioral scientists, such as Pavlov or Thorndike, did not attach great importance to how the storage in memory and the future recall would take place. All behavior could be explained without having to consider internal mental states or the learner's consciousness (Skinner 2011). Learning was viewed as mostly passive, and it occurs in environments where intensive, environmental stimuli exist. The acquisition of habits has been discussed with the assumption that regular use of the activity serves to maintain the learner's responsiveness (Schunk, 1991).

2.2.2 Intentional learning strategies

Learning strategies are humans' internal programs for the control of learning processes. They range from techniques for improved memory to better studying or test-taking strategies. Explicit learning is intentional due to the use of a learning strategy (Schnotz, 2006).

Behavioral research guides many teacher-centered learning strategies. These strategies have proven to be reliable and efficient approaches to facilitating learning (Ertmer & Newby, 2013), in terms of:

- learning objectives for achieving desired behavior (remembering facts)
- generalizations (defining and illustrating concepts)
- associations (explaining procedure or mnemonics strategies)
- concatenations (automatically carrying out a certain procedure)

Feedback as reinforcement

Self-directed learning can be explicitly designed for behavioral modification when consciously setting goals, selecting appropriate strategies, monitoring, and modifying the learning process (Schnotz, 2006). The law of Thorndike's exercise is known as *learning by success*. This law has been extended as learning design, for instance, in problem-solving contexts of productive failure with try and error approaches. Feedback as reinforcement is an effective teaching strategy when the quality of the input is based on diagnostics and analysis. Feedback such as "that's correct" or "that's wrong" is considered ineffective (Cooper, 1993).

2.2.3 The machine as an instructor

Pressey: The inventor of teaching machines

In 1924, Sidney L. Pressey (1926) invented the first teaching machine (see Figure 1) to support education on assessments with the principle of stimulus-response learning. The mechanical apparatus could reproduce the teaching material (drill material) and promoted fast reflex action according to the Pavlovian style. The machine managed multiple-choice questions and returned success points for correct answers (Pressey, 1926, 1927). It could be adjusted in a way that it would continue only when the student achieved the right answer. The teaching machine was the primary medium in education until the 1960s. Pressey, it is worth noting, was also a contributor to *programmed learning* (Skinner 1961) which was founded by Burrhus F. Skinner (1961).

Skinner: The inventor of Programmed Learning with multiple-choice methods

Skinner (1961) was enthusiastic about the efficiency of Pressey's machines. He sought to improve them using Thorndike's scientific theory of *operant conditioning* (Skinner, 1974). Skinner designed the machine to influence a person's behavior in a particular learning situation by positive or negative reinforcement. He described the method of automated instructions and immediate feedback as *Programmed Learning*. The pace of learning could be adjusted to suit the individual. The machine offered small task units by linear sequence with immediate and uniform reinforcement of increasing complexity (Cooper, 1993). Skinner carried out many tests and consistently obtained "positive" results. The students were interested and attentive and learned efficiently by quickly generating the desired behavior of the teacher (Skinner 1961; Skinner & Holland 1961).

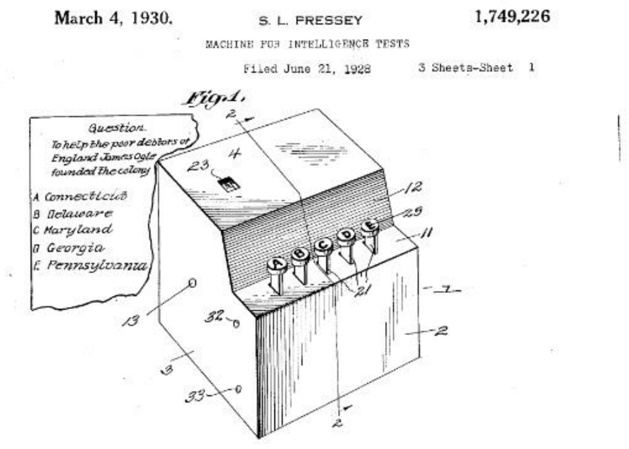


Figure 1 Excerpt of the patent for a machine for intelligence test from Pressey 1930[3]

Pressey: Reinforcement is not a significant process of learning

Motivated to improve the workload (in terms of volume and efficiency) of teaching, Skinner and Thorndike focused on more efficient teaching strategies such as automation, feedback, and learner's self-control

[3] https://patents.google.com/patent/US1749226 (18.11.2019)

(Tomlinson 1997). Likewise, Pressey (Pressey 1927) predicted that the spread of machines would lead to many savings in time and costs. The goal was to automate education and to free teachers and students from hard, tedious, and repetitive workloads. Yet, in his publication Teaching Machine (and Learning Theory) Crisis (Pressey 1963), Pressey, in response to Skinner and Thorndike's (Skinner and Holland 1961; Woodworth & Thorndike 1901) work, argued that reinforcement does not constitute the significant process of learning and can have destructive consequences on cognitive structure.

2.2.4 Impact on technology-enhanced learning

The principles of Pressey's teaching machines are widely used in education today. In technology-enhanced learning (TEL), stimulus-response learning is widely used to evaluate the learning process or to engage and motivate learners in gamified aspects. Feedback is one of the top influences on student achievement and has an effect size of d=0.79 (Hattie 2013).

Michel et al. (2015) evaluated different educational assessment strategies for higher education. They found that TEL assessments are designed for diagnostic and formative evaluation (d= 1.13)[4], which are popular in learning management systems (LMS) (see Section 0) or classroom response systems. These assessment types contain substantial collections of closed questions such as multiple-choice, assignment, sorting, short text, or gap text and enable lecturers to conduct massive student quests with little effort and fast response.

Feedback through classroom response systems

Feedback systems, such as the first classroom response systems (CRS), were implemented more than 20 years ago and are still popular today, in lectures with large student numbers. Dufresne et al. (1996) presented on Classtalk a CRS to gather misconceptions by examining students with conceptual questions, including the correct and wrong answer. The second functionality of Classtalk was teacher-student interactions to create an atmosphere of commitment and stimulate engagement. Elena Silva (2009) published a CRS that gave personalized feedback on higher-order thinking tasks such as simulation analyses of virtual learning environments. The EduApp of ETH Zurich was a mobile CRS that provided lecturers the state of students' prior knowledge during the lecture with mobile technology (Korner et al., 2013).

[4] The statistical measure effect size created great interest in educational research when Hattie (2013) published visible learning to relate educational factors with student performance. Background information and a selection of educational factors that are relevant regarding LBML are explained in Appendix I.

Motivation through pointsification

Tools with game mechanics, such as a quiz, often show stimulus-response behavior and incentive strategies (Browne, Anand, & Gosse, 2014; Burke, 2016; Scekic, Truong, & Dustdar, 2013; Wibisono, 2019). The goal of games is to motivate players and it is for this reason that game mechanics are widely used in educational contexts, known as *gamification* (Hamari, Koivisto, & Sarsa, 2014). Gamification can support user engagement and motivation. The key patterns are response behaviors such as user activity, social interaction, and productivity of actions (Hamari et al., 2014). Tools like Kahoot that award users with points are used as ice breakers to increase motivation for attending lectures (Wibisono, 2019). Kifetew et al. (2017) used the concept of *pointsification* and awarded students with points that lead to increased student engagement, attention, and perceived usefulness. Nicholson (2012) stated that pointsification situates the learning activity and commitment with the result, that the demand for immediate rewards increases and they deeply engage students in an activity, often enabling them to reach higher-order thinking skills (Hamari et al., 2014; Naismith et al., 2004).

Yet, the adverse effects of pointsification and rewards are undermining the original, intrinsic motivation of learning (E. L. Deci & Ryan, 2000; Dweck, 1986). The differences between intrinsic and extrinsic motivation are defined by Deci and Ryan (1985) through their *Self-determination Theory*. This theory demonstrates that extrinsic motivation can lead to intrinsic motivation through the increase of self-determination and autonomy.

As with Maslow's *Hierarchy of Needs Theory* (Maslow, 1943), Deci and Ryan's (1985) *Self-Determination Theory* structures the sources of motivating energies of action, according to physiological needs (e.g., breathing, nutrition, sleep), emotions (e.g., curiosity), and the psychological needs autonomy, competence and relatedness. The three needs have the following meaning:

Motivation through autonomy, competence, and relatedness

- **Autonomy** means room for action, choice, decision-making, and self-regulation (E. Deci & Ryan, 1985).
- **Competence** means to seek to control the outcome and actively experiencing the effectiveness of one's actions (E. Deci & Ryan, 1985).
- **Relatedness** means to seek a connection to others and to experience caring for others. These are the peers as well as the associate teacher of the student (Grolnick & Ryan, 1987).

Autonomy and learning success is most effective when teacher-centered learning controls present options, whereby a learner can choose one based on their interests (Grolnick & Ryan, 1987). Competence is experienced through individual and qualitative feedback, and the optimal level of a task's complexity through adaptive teaching (E. L. Deci & Ryan, 1993).

Relatedness occurs in group work and other collaborative designs (see Section 2.4.4.1). Social evaluation, comments, and observations (peer assessment) are appreciated by learners and stimulate the reflection of their learning behavior (Naismith et al., 2004).

Rewards only as deficiencies

Deficiencies of gamification arise when the undermining of intrinsic interests occurs. Quizzes with poor game designs, and no meaningful connection to the learning objectives, neutralize the stimulus (Browne et al., 2014; Nicholson, 2012). The uselessness of a gamified application results when users cheat on the education system because the application offers the only incentive to evaluate learning progress (GalOz & Zuckerman, 2015; Hamari et al., 2014).

Undifferentiated feedback as deficiencies

Deficiencies of feedback regarding the behavioral triad (stimulus, response, and feedback) arise in coded forms of assessment, such as the reproduction of learning with right/wrong answers (Michel et al., 2015). Indifferent feedback on the learning achievement can affect the self-concept, according to Bernhard Weiner's (1972, 1985) *Attribution Theory*. Weiner's theory claims that humans attribute results to effort, ability, level of task difficulty, or luck. Depending on the ability attribution of a learner, success or failure have different cognitive consequences on the learner's expectation of success. Low performers with higher self-esteem, and who consider themselves stable (performance through ability), expect failure at a later date. Low performers, with high self-esteem, and who believe their ability is variable (performance through learning effort), expect future success if they work hard (Weiner, 1972, 1985). Ziegler and Heller (2000) determine that personalized (qualitative) and motivational feedback improves a learner's self-concept. High motivation arises when feedback is based on effort, on exemplary models (Bandura, 1976), or on operant reinforcements (praise, facial expressions, and gestures) (Ziegler & Heller, 2000).

2.2.5 Relevance to this dissertation

The previous sections explained how stimulus-response pedagogy makes use of technology, how this teaching style affected teaching and learning one hundred years ago, and its effects today. They elaborated on the positive effects, such as classroom response systems that verify the student's prior knowledge and adaptive instruction to offer feedback on assessments to trigger intentional and metacognitive learning strategies. Behaviorist drill-and-practice approaches are shown in educational games with rewards or pointsification to engage and motivate learners. However, behaviorist approaches show limitations in the development of higher-order thinking skills. The good usability of multiple-choice survey tools and applications poses the risk that designers will only create designs with poor pedagogy. This risk relates to research question **RQ1** (regarding key features of a state-of-the-art LBML system with multimedia capabilities) as it pertains to providing behaviorist tools or interfaces. It relies on research question **RQ2** with the question of how and for which purpose (prior knowledge, feedback, motivation, transfer of learning) teachers implement LBML design with closed-ended, multiple-choice, or rating questions from the stimulus-response systems tradition. Intentional learning strategies, such as the association, concatenation, or self-directed strategies presented in Section 2.2.2, are part of the research question **RQ3** and are discussed in the studies of Chapters 3 and 4. The results reveal how students perceive the LBML activities and if and how they make use of learning strategies, including the behaviorist ones. Chapter 4 illustrates how sustainable these strategies are in terms of their long-term effects.

2.3 Knowledge acquisition and computer-assisted instruction

The 1960s are regarded as the cognitive revolution, with the introduction of cognitivism as a new learning paradigm. Bruner (1966), Piaget (1954) and Gagne (1965) were the key educational researchers. In cognitivism, the focus centers on mental structures within the brain and how humans acquire, retain, and recall information, impressions, sensations and experienced thoughts (Schnotz, 2006).

In contrast to the behavior-supported stimulus-response approach, the cognitive process encompasses *knowledge acquisition* as well as the *elaboration process into the existing schema* of individuals. Piaget (1954) researched the complex cognitive structures of knowledge acquisition and developed the *theory of cognitive development*. Bruner (1966) expanded the *Theory of Instruction* with a focus on *prior knowledge,* which facilitates the active learning process. Bloom (1956) and Krathwohl et al. (1964) proposed the taxonomy of cognitive and affective educational goals, which proved highly valuable in the analysis of teaching outcomes and the design of instructions. Robert Gagne (1965) then published *The Conditions of Learning* and established the study of learning objectives in individual levels of complexity. He then linked the levels with suitable curricula of different subjects.

Bloom's taxonomy of cognitive and affective educational goals

2.3.1 Learning as knowledge acquisition

Learning as knowledge acquisition is more learner-centered than learning by reproduction (rote learning), as it involves the possibility of acquiring vastly different content with different methods (Neubert et al., 2001). Knowledge acquisition is understood as the construction and continuous modification of knowledge representations in the form of more logic and higher rationality (Woolfolk Hoy & Schönpflug, 2008). Reward appears following the attainment of in-depth understanding while the negative experience follows the learning of incorrect understanding (misconception) or unnecessary knowledge (Neubert et al., 2001).

Learning consists of the human acquisition and information processes, as well as memory for memorizing and retrieving information (Woolfolk Hoy & Schönpflug, 2008). Ill-structured problem-solving learning, which has not predefined goals, makes productive use of existing cognitive structures (principles, core ideas, strategies, and general schemes). Elaboration is the act of adding further information to existing structures to create a more complex structure. This process is called *Transfer of Learning*, which Edward Thorndike introduced (Woodworth & Thorndike, 1901).

Figure 2 illustrates the structure of human memory. It consists of three stages: sensory; short-term; and long-term memory (Cowan, 2008), as follows:

Sensory memory retains impressions immediately (2 seconds) after the original stimuli are received through the five senses (sight, hearing, smell, taste, and touch). A part of the perceived stimuli passes to the short-term memory (Woolfolk Hoy & Schönpflug, 2008).

Short-term memory can, simultaneously, remember and process information to build mental constructs (schemas). This memory is used for active working and is limited in both capacity and duration (cognitive load). The *Information Processing Theory* (Miller, 1956) notes that short-term memory temporarily stores 5-9 knowledge units as compressed chunks (known as memory span). *Cognitive Load Theory* (Sweller, 1994) contends that a full short-term memory impedes new learning. With memorization, the information in the short-term memory repeats several times (memorizing) to reach long-term memory (encoding). During encoding, information links to semantics (meaning). Semantics is the prior knowledge that promotes chunking with the information (Cowan, 2008). Examples, contextualization and the simulation of contradictions help to develop the link between prior knowledge and new knowledge (Woolfolk Hoy & Schönpflug, 2008).

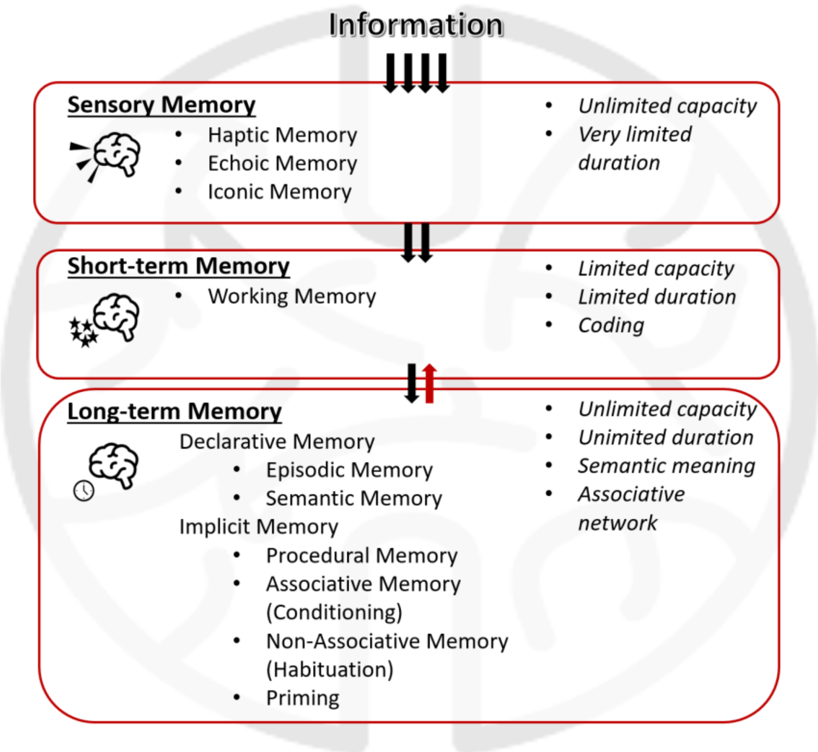


Figure 2 Classification of human memory (Camina and Güell 2017)

"*People learn more deeply from words and pictures than from words alone,*" stated Mayer (2005, p. 31), using the *Cognitive Theory of*

Multimedia Learning (see Section 2.3.4). This principle is shown, for example, when students analyze a complex map. Here, a verbal explanation is more important than the map itself as a complement to learning success. Additional text is ignored due to the cognitive load of the visual mode. The *Dual-coding Theory* states that the verbal and visually explained learning content in short-term memory is separately encoded and linked in verbal and visual terms to obtain elaborated in long-term memory (Mayer, 2005). Three main assumptions underline Mayer's Cognitive *Theory of Multimedia Learning*, namely dual-channel, limited capacity, and active processing as discussed:

- **Dual-Channel:** Two separate channels (audio and visual) encode information according to the *Dual-Code-Theory* (Paivio, 1986).
- **Limited Capacity:** Each channel has a limited capacity according to the *Cognitive Load Theory* (Sweller, 1994).
- **Active Processing:** Learning is an active process of filtering, **s**electing, **o**rganizing, and **i**ntegrating information based on prior knowledge according to the ***S**electing-**O**rganizing-**I**ntegrating Model* (Mayer 1999).

Short-term memory does not interpret a multimedia presentation of words, images, and auditory information in a mutually exclusive way. Instead, it dynamically selects and organizes these elements in combination based on the limited capacity to generate logical mental constructs aligned with prior knowledge.

Bloom's (1956) Taxonomy of Educational Objectives

Long-term memory encodes information declaratively for storage in episodic memory (own experiences with space and time information) or semantic memory (facts, general knowledge, etc.). Implicit encodings are stored as procedures (skills, internalized rules, etc.), perceptions (habituation), conditioning (conditioned reactions), and priming (implicit activation of concepts) (Woolfolk Hoy & Schönpflug, 2008). On this basis, Bloom (1956) sorted learning outcomes into three domains. The cognitive domain encompasses the recall or recognition of knowledge and the development of intellectual abilities and skills. The affective domain deals with attitudes and motivation. The psychomotor domain includes manual or physical skills or the performance of actions. Based on Bloom's (1956) taxonomy, John Anderson (1982) proposed the acquisition of cognitive skill such as second language learning in factual, conceptual, procedural, and metacognitive dimensions. The categories of the cognitive process were differentiated from lower-order thinking skills to higher-order ones. Anderson, Krathwohl, and Bloom (2001) revised this approach by replacing "synthesize" with "create" and situating it at the top level (see Table 1).

Lower-order thinking skills →					Higher-order thinking skills
1 Remember	2 Understand	3 Apply	4 Analyze	5 Evaluate	6 Create
recognizing recalling	interpreting exemplifying classifying summarizing inferring comparing explaining	executing implementing	differentiating organizing attributing	Checking critiquing	generating planning producing

Table 1 Structure of the cognitive processes dimension (Anderson et al. (2001). See Krathwohl 2002)*)*.

This taxonomy for learning, teaching, and assessing is the pinnacle classification of educational objectives today. Creativity, within this taxonomy, is a key competence.

2.3.2 Instructional teaching strategies

Instructional teaching strategies are characterized by acquiring knowledge through instruction (Schnotz, 2006). Learning content is acquired in the way that the teacher transmits the information to them, or in the way that it is presented in teaching material (Woolfolk Hoy & Schönpflug, 2008). Knowledge and skills as learning content are presented generalized as terms, rules, laws, or theories and are systematically explained and demonstrated by the instructor. Subsequently, the acquired knowledge is transferred from one situation to another, as described in the *Drill and Practice* procedures of Skinner's (1961) *Teaching Machine*. This method actively supports the consolidation and transfer of knowledge to prevent *inert knowledge* (knowledge which one can not use for effective problem-solving). The regulation of teaching instruction can be varied didactically by direct or adaptive instruction (Schnotz, 2006):

- The teacher actively regulates **direct instruction**. Classroom instruction begins with the introduction of the lesson topic, learning goals, and a pre-organization tool, such as the *Advanced Organizer* (Ausubel, 1960). This process illustrates the connection between what students will learn and the information - or learning - they have already received. The teacher presents the learning content and objectives, poses questions and answers throughout, and concludes with a collective reflection. The transfer of knowledge is individual and independent of the instruction (Hasselhorn & Gold, 2009). The advantage of direct instruction is the transmission of dense information while teaching, and, subsequently, it has an effect size of d=0.60 (Hattie 2013).

However, if the cognitive stimulation of the presentation is low, learners process the knowledge only passively and receptively (Schnotz, 2006).

- **Adaptive instruction** attempts to adapt the control of instruction to the individual learner. This is achieved by adjusting the time made available for specific learning activities (learning time differentiation), and by individually adapting learning objectives and teaching methods (Hasselhorn & Gold, 2009). Adaptive instruction is implemented in various forms, such as the model of *Cognitive apprenticeship* (Collins, Brown, and Newman 1988) (see Section 2.4.4.1) or via online media, such as **Blended Learning** (Flipped Classroom) (Kale, Marathe, Patel, & Vanjari, 2017). Adaptive instruction has an effect size of d= 0.23 (Hattie 2013).

Meta-analysis of effective teaching (Hattie, 2013) demonstrates that in addition to the learner's expectations (d=1.44) and prior knowledge (d=0.93), teacher's actions, such as scaffolding (d=0.82), classroom discussion/listening to learning (d=0.82), feedback (d=0.75), problem-solving teaching (d=0.61), and presenting goals while teaching (d=0.50), influences and advance learning from surface to deep knowledge. Bloom (1956) contends that the time factor is of central importance. He argues that, in principle, all learners can achieve the assigned goals if they receive sufficient time to master the learning goals (Cooper, 1993; Schnotz, 2006). Learners with difficulties, however, may require not only more time, but also structured and direct instruction (Weinert, 2001).

Mastery Learning through Instructional Design

Instructivist learning scholars have developed unique methods for teaching. Through his *Instructional Design,* Robert Gagné developed the *Mastery Learning Method* (Robert M Gagne & Briggs, 1974) and advocated the systematic didactic planning, development, and evaluation of learning environments (Reinmann & Mandl, 2006). In this setting, the material is divided into relatively small learning units, each with its objectives and formative assessment. Each unit is preceded by short diagnostic tests, which provide information to identify gaps and strengths. Learners do not move on to new learnings until they have mastered the previous and primary material. Mastery learning requires a large number of tight feedback loops based on small units of well-defined, well-matched, measurable outcomes (Robert M Gagne & Briggs, 1974).

2.3.3 The computer as an instruction assistant

In the 1960s, the computational support mastery learning grew. During this period, large, decentralized computers, called mainframes, dominated the computer world. The first computers, such as the IBM 1500 (see Figure 3), served as learning assistants in the classroom. Their purpose was to support so-called computer-assisted instruction (CAI) (Baker, 1971). The concept of CAI was inspired by Skinner's (Skinner & Holland, 1961) Programmed Learning, which propagated short sequences of teaching material presented at an adaptive pace. Figure 3 depicts the learning environment with mainframe computers and computer programs with audio-visual capabilities that allowed the answers of the learners to be collected, analyzed and filtered before the next task was presented.

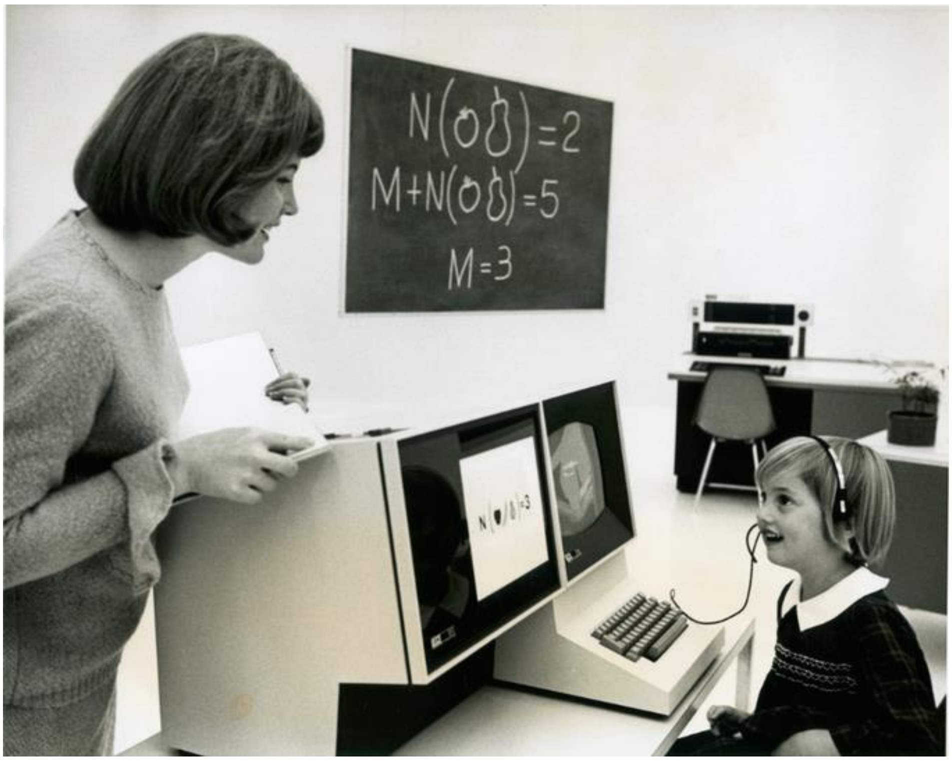


Figure 3 Computer-assisted instruction in the classroom with the IBM 1500 in 1966[5]

Brudner (1968) was one of the first advocates of CAI for teaching. He predicted a revolution in teaching and learning and postulated that CAI would play a significant role in transforming the educational process. He believed it a significant advantage that teachers were provided a sophisticated tool that enabled flexible, multimedia, individualized instruction at a relatively small increase in cost. However, Brudner underestimated the complexity of the learning process and the necessary tools on the computer required for large-scale implementation of CAI at educational institutions (Coulson, 1962). The richly equipped CAI

[5] https://twitter.com/ibm/status/535870716999393282 (18.11.2019)

computers with functions such as test results, diagnosis, prescription, and reporting, were not convincing the practicing teachers due to the heavy workload of the administration of the teaching resources and showed therefore only the theoretical feasibility of CAI learning. The proof of concept was performed under laboratory conditions, ignoring practical approaches required for the real world (Coulson, 1962).

2.3.4 Impact on multimedia instruction

CAI with multimedia, such as educational video, has become an integral part of today's teaching culture for more than a decade and is now the primary tool for individualized instruction (Kerres, 2013). In the classroom, however, instructional teaching still remained a predominant feature, and the advent of multimedia instruction has meant that in many places there has been a shift from blackboards to PowerPoint (Craig & Amernic, 2006). The impact of PowerPoint was even more profound than just a substitution according to Puentedura's (2006) educational technology adoption framework (SAMR – Substitution, Augmentation, Modification, Redefinition). Presentation materials such as PowerPoint slides, professional articles, textbooks can be shared online for individualized instruction as well, designated as virtual instruction or e-learning (Kerres, 2013). Furthermore, the digitality of teaching material opens up a whole new range of possibilities. Options include searchable information or editing, such as add, update, delete, copy, and paste text. Students can rewrite course material within a lecture and complement their learnings individually and effectively (Neubert et al., 2001). Instructors benefit from the preparation of teaching materials on recycling, exchange, and open educational resources (Wannemacher & Kleimann, 2005; Zhang et al., 2004), and through new presentation techniques such as multimedia and interactivity.

Novelty factor bias in educational technology studies

Zhang et al. (2004) empirically investigated the cognitive and affective learning outcomes between traditional classroom teaching versus e-learning. The students of the e-learning group performed better. They appreciated the learner-centered and self-pace approach, the time and location flexibility, and the archival capability in terms of content reuse. In their study, Craig and Amernic (2006) compared the participant’s attitude towards overhead projector slides to PowerPoint slides, with the latter slides achieving significantly better results. The reason for the significant increase in learning motivation was not fully established. Craig and Amernic assumed that, as with similar studies, the reported results were likely influenced by a now-defunct “novelty factor.” McLuhan & Fiore (1967) would likely support this position, given their publication, "The Medium is the Massage". Though their paper was unintentionally titled and published as “massage” instead of “message”, they refrained from correcting it as they felt that new technologies had a "calming, pleasant and relaxing effect" (Ong, 2013). This belief is supported by both the *Representation Theory* (Jerome S. Bruner & Olson, 1973) and the Dual-code Theory (Paivio, 1986). Both Zhang et al. (2004) and Craig and Amernic (2006) reported similar effects of the dominance of technology in the learning process, and its possible ability to influence the perceptual and emotional abilities of the teacher-learner relationship. Despite the teacher's active encouragement to ask questions, students in the study did not ask questions. Craig and Amernic (2006) concluded that the Socratic-like free performance would form a more direct, sociable, and collaborative relationship with the audience - a position supported by the *Conversation Theory* (Pask, 1976). Postman (2011) posits, however, that in good instructional teaching, visual instructional materials are only for support. Oral presentation and interaction remain the central medium. Nonetheless, the introduction of PowerPoint slides illustrates the digital transformation of education. The introduction of technology has various intended and unintended effects, ranging from facilitation and moderation of teaching to communicative changes in the teacher-learner relationship (Baecker, 2007).

Multimedia as a construct of multicodality, multimedia, and multimodality

Another way of using instructional technologies is to present content through various channels known as multimedia. The concept of multimedia has lost its technical meaning in the sense of a combination of technical means to convey information. Multimedia describes a construct of the three essential dimensions, namely: multicodality, multimedia, and multimodality (Weidenmann, 1997), as follows:

- ***Multicodality*** describes the type of encryption represented as sensors, such as hypertext, to represent text.
- ***Multimedia*** describes the type of channel or interface, such as books, videos, audiobooks, and e-books.
- ***Multimodality*** describes a kind of physiological reception. This is mostly auditory and visual in CAI.

Effective teaching instruction strategies with multimedia are simulations, visualizations, or animations. These strategies allow realistic exercises of learning content, which can activate higher-order thinking (Kerres, 2001). However, perception is of crucial importance in the mediation of multimedia content. Information should be distributed specifically to the verbal and visual modality, which would facilitate recall knowledge, as asserted by the *Representation Theory* (Jerome S. Bruner & Olson, 1973) and the *Dual-coding Theory* (Mayer, 2005). Dual coding is described in Mayer's (2005) *Cognitive Theory* of Multimedia Learning. Its first principle is the Multimedia Principle (Dual Coding) that explains that people learn better from words and images than from words alone. Mayer

(2005) demonstrated that a significant alternation of auditory and visual material is experienced as pleasant by the learners and increases their acceptance. But there are also differences within visualizations. Learners perform better with animation than with static images (Münzer, Seufert, & Brünken, 2009). Concerning animated map designs, however, depends on what kind of representational tasks are required (Harrower & Fabrikant, 2008).

Multimedia learning principles

Multimedia learning has been tested through a variety of studies. These studies have produced further findings and principles of multimedia learning (see Mayer 2009):

- ***Spatial Contiguity Principle*:** People learn better when corresponding words and images are closely situated on the page or screen.
- ***Temporal Contiguity Principle:*** People learn better when corresponding words and images are presented simultaneously and not consecutively.
- ***Coherence Principle*:** People learn better when unnecessary words, images, and sounds are excluded.
- ***Modality Principle:*** People learn better from graphics and narratives than from animations and texts on the screen.

Motivational factors according to Keller's (1987) ARCS model

To date, digital content has been viewed from a purely process-oriented perspective. The main problem with instructional design theories is the lack of motivational aspects (Mayer, 2009). In contrast to the motivational models of Deci and Ryan (1993) and Maslow (1943) (see Section 2.2.4), the ARCS model of Keller (1987) comprises the specific aspects of motivationally adaptive computer-assisted instruction. According to this theory, four factors influence motivation:

- **Attention** (A) - the content must be visually or task-specific exciting and diverse.
- **Relevance** (R) - the content should have something to do with the learner's goals or motives, and relate to the real world.
- **Confidence** (C) - confidence in successful achievement.
- **Satisfaction** (S) - satisfaction with the result.

Guidelines for good instructional design

Song and Keller (2001) empirically examined the effects of a prototype of motivationally adaptive CAI based on the ARCS model. They compared three treatment conditions: motivationally adaptive, motivationally saturated, and motivationally minimized CAI. The adaptive instruction resulted in higher effectiveness, overall motivation, and attention, compared to the other two CAI types. One reason for this was that the use of a menu-driven program structure allowed learners to control access to different parts of the course. The ARCS model also shows that poorly designed e-learning systems promote frustration, uncertainty, and a reduced interest in learning (Zhang et al., 2004). With instructional material of a passive and receptive nature, learners have little control over their interest-driven learning process. A three-hour learning video without the possibility to ask questions, to get in touch, or to reflect in exchange and to receive positive feedback, reduces the degrees of freedom and pleasure (Petko, 2014; Zhang et al., 2004). Zhang et al. (2004) postulated that e-Learning could not replace classroom teaching as a community activity. Learning is a social-cognitive activity and requires social inclusion (E. Deci & Ryan, 1985), which e-learning cannot wholly substitute. E-learning requires more self-discipline and personal responsibility due to the self-regulated learning approach. Vilamil-Casanova and Molina (1996) provided eight rules for the interface design of multimedia learning content, which also support guidelines that are effective for cognitively weaker learners: keep the cognitive load low; avoid dividing attention; use the media to direct attention; keep important information visible; encourage rehearsal; use concrete words and multiple media; design effective exercises; or, create realistic simulations.

However, despite the motivational effects on multimedia learning, Münzer et al. (2009) contend that multimedia content will often only be consumed superficially and receptively. In consequence, multimedia learning will produce inert knowledge that can not be applied for problem-solving in realistic situations. Yet, for learning success, elaborating thoroughly on content is crucial. To this end, learners must be encouraged to employ cognitive and metacognitive strategies to "overcome" minor difficulties.

Interactivity of the instructional design

Interactivity is an essential structural characteristic of adaptive learning (Weidenmann, 1997). Control elements, for example, afford the user control to: regulate the presentation speed of audio or video (stop, forward, back); watch a video several times; retrieve help or additional information for individual text passages or pictures; find certain places quickly by search commands; or, be able to follow up cross-connections (Niegemann, 2008). Conversely, the *Cognitive Load Theory* (Sweller, 1994) shows that the more diverse a medial learning offer is set up - with regard to coding, modalities, contents, and structures - the greater the danger that learners are overloaded and that diversity leads to orientation and concentration problems (Weidenmann, 1997). Therefore, (Niegemann, 2008) suggests to extend the user control to some extent by algorithms and to support the user demonstrating this, in the work of Krishna Prasad and Aithal (2017), location sensors enable the adaptation of conceptual or content-related teaching processes depending on the geographical location of the learner. The content of the user-specific curriculum is adapted when the user is absent more than two weeks from his/her home location, which was registered by the user's mobile phone.

2.3.5 Relevance to this dissertation

While behaviorism deemed that learning is based on stimuli and is shown in observable reactions, the cognitive revolution by Bruner (1966), Piaget (1954), and Gagne (1965) stated that learning is elaborated by the human brain, and new information is acquired through the assimilation into or the accommodation of existing information (prior knowledge). The *Cognitive Multimodal Learning Theory* of Mayer and Moreno (2003) stated that better understanding and elaboration of new information could be achieved through engaging a number of senses—visual, auditory, tactile—during learning. Multimedia deals with research question **RQ1** regarding the main features of a state-of-the-art LBML system that offers a variety of media, such as text, images, maps, and audio and video functions. The four case studies in Chapter 3 and the activities in the experimental study elaborated different teaching designs (**RQ2**) using multimedia to engage learners, and the results were gathered through direct observation, focus groups, and interviews to provide an answer for research question **RQ3.** The research questions **RQ2** and **RQ3** are further answered through the analysis of the teaching design and learning outcomes of the case studies in Chapter 3 with respect to the consideration of learners' prior knowledge, teaching methods, learning time, and learning objectives based on Bloom's (1956) taxonomy. For sound instructional designs, the ARCS model (Keller, 1987) suggested guidelines for thoughtful planning and preparation that focus on the motivational aspects of the learning environment. The qualitative study of the teaching design (**RQ2**) and learning outcome (**RQ3**) of the experimental study in Chapter 4 involves the motivational aspects through the students' self-assessments. Chapter 5 presents another attempt to track motivation in LBML scenarios based on the physical dynamics of moving learners.

2.4 Knowledge construction and networked computing

Constructivism emerged in the 1970s as a new learning paradigm. The work of cognitive psychologists Bruner (1966), Piaget (1954), Vygotsky (1978), and Dewey (Dewey & Boydston, 1938), the pioneer of constructivism characterized this paradigm shift. These psychologists argued that the acquisition of knowledge and the building of competence went beyond the mere acquisition of pre-defined knowledge. Bruner (1966) distinguished between the old world of passive, receptive learning and the new world of active, problem-based learning. Piaget (1954) and Vygotsky (1978) believed that learners prefer to acquire concepts and theories through direct experience with the real world (Piaget, 1954) or, defined in other terms, social communities (L. Vygotsky, 1978). Dewey (1910) was the innovator of discovery and pragmatic learning and gained significant attention through the "Learning by Doing" approach.

2.4.1 Knowledge construction as discovery learning

Learning is an act of construction and goes beyond the acquisition of knowledge through instruction and reproductive learning (Neubert et al., 2001). Constructivism assumes that education is an active, constructive process. Learners construct new knowledge as their own representation of objective reality on the basis of their prior knowledge and their own experience (Neubert et al., 2001). Awareness and knowledge arise from practical activity, and they require personal experiences. The mental representation of new information is, therefore, fundamentally subjective. The greatest negative experience is the insufficiently self-regulated learning process. The learning process is accompanied by continuous metacognition, in which the learners actively reflect on the changes in their own knowledge construction (Neubert et al., 2001). Criticisms of the constructivist learning process are that the formation of conceptions can lead to cognitive overload and cognitive misconceptions and that it raises difficulties for teachers in terms of identifying problems and misunderstandings (Woolfolk Hoy & Schönpflug, 2008).

2.4.1.1 Piaget's concept of biological, cognitive development

Process of equilibration with assimilation and accommodation

Piaget's theory of Cognitive Development (1954) suggests that the learning process is a biological, structural-genetic maturation process. This process is facilitated by interaction with environmental influences in the form of cognitive conflicts. The learner first constructs his reality from a new experience (stimuli from the environment) that is first assimilated into an existing scheme. For example, contradictions or differences of opinions are clarified through productive learning dialogues or experiments. If necessary, perception is changed in a way that the existing cognitive structures (schemata) are sufficient to cope with the situation. If the assimilation does not fit properly, cognitive disequilibrium results. The existing schemes must be elaborated and adjusted so that they will correspond to reality and to ensure they are useful for future problem solving (Piaget, 1954). Accommodating the scheme brings the learner to cognitive equilibrium until new assimilation compromises the scheme again. This cycle of adaptation and accommodation is known as “process of equilibration” (Bormanaki and Khoshhal 2017). The resulting conflict between inner-schematization and a comparison with the environment is defined as “knowledge construction” (Neubert et al., 2001).

Piaget’s (1954) findings were based on observations of his children. He recognized that children go through four stages of mental development, each of which is reached by cognitive development, maturation, active experience, social interaction, and striving for balance. Adolescents (aged 12) are in the final stage of mental development and can think abstractly, theoretically, and hypothetically about problems, including the incorporation of moral, ethical, social, and political issues. Adolescents can move from a general principle to specific information by means of deductive logic or argumentation.

2.4.1.2 Vygotsky's concept of cognitive development through collaboration

Zone of proximal development

Piaget’s (Piaget and Inhelder 1967) findings were strongly reflected in those of Vygotsky's (1978), though the latter scholar emphasizes the cultural learning environment. Vygotsky’s *Cognitive Development Theory* argues that cognitive abilities require guidance from a knowledgeable person. He called his theory *The Zone of Proximal Development* (ZPD) with the meaning that “*the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem-solving under adult guidance, or in collaboration with more capable peers*” (Vygotsky, 1978, p. 86).

Vygotsky’s ZPD in the educational context means that the learning environment should be designed with options of social construction of knowledge rather than acquiring or reproducing existing knowledge (Neubert et al., 2001). Teaching is reduced to guided participation and scaffolding.

2.4.1.3 Dewey's concept of cognitive development through action

"Learning by Doing"

Dewey (1910) represents a progressive approach to education, by way of emphasizing the need for learning through "Learning by Doing." Dewey believed that people learned through a "pragmatic" approach - that learning requires a lived experience. Dewey and Boydston (1938) postulated with their *Engagement Reflection Theory* that experiences and interaction within the learning process are significant for effective learning. Collaborative inquiry, manipulation, and understanding should take place outside of the school space and synthesizing and reflecting the experienced content should be done collectively in the classroom space. Dewey's (1910) envisaged the classroom as being rooted in democratic ideals where the equal voice of all participants in the learning experience was promoted. He also believed in an interdisciplinary curriculum that connects the subjects. His vision was that students work freely inside and outside the classroom to enrich their knowledge intrinsically (Ellis & Fouts, 2001).

Engagement Reflection Theory

2.4.1.4 Bruner's Theory of Cognitive Development through problem-solving

The act of discovery

Bruner's (1961) theory, *The Act of Discovery*, describes learning as an inductive and research-based learning process, whereby environmental interactions form concepts. The learner faces a problem situation and creates hypotheses based on their existing knowledge. The learner then explores and experiments with the problem to establish facts and rules and learn how to act with the environment using the new rules. The concepts serve to categorize, simplify, and operationalize the world (Hasselhorn & Gold, 2009).

Learning is a socio-constructivist process

All four approaches - The Process of Equilibration *with Assimilation and Accommodation*, *Zone of Proximal Development*, *Learning by Doing*, and *The Act of Discovery* - assume that learning is a constructive process. The theories state that cognitive learning is based on experiences with the environment in combination with the development of one's own attitudes, values, beliefs, patterns and prior knowledge (Neubert et al., 2001). The learning focus is not ontological ("what" questions), but epistemological ("how" questions) (Pörksen, 2011). Constructivism thus departs from the idea of absolute truth and empirical objectivity, because the observant learner is not independent of knowledge. The interactions with peers are crucial and determine how learning is assumed, continued, and developed (Neubert et al., 2001).

Learning success occurs when the learner undertakes an action-orientated approach, meaning they are self-motivated, organized, and reflective in the way they learn. Learning success further occurs when the learner takes an outside perspective, meaning to look at himself/herself from the outside to observe gaps, misconceptions, and difficulties in their learning and to open up new and creative ways to change their learning behavior.

2.4.2 Constructivist teaching strategies

Conceptualization by concreteness fading (enactive to iconic to symbolic)

Bruner (1966) argued that in constructivist knowledge acquisition, the degree of complexity of the learning content is decisive and depends on the maturity and prior knowledge of the learner. If the first contact of the learning content is, for example, not an action but presented in symbolic form only, the high degree of abstraction routinely problematizes the understanding of underlying concepts (Anderson, Reder, and Simon 1996; Klafki 2007; Lave 1988). Applying his *Act of Discovery Theory*, Bruner (1966) investigated different types of strategies of concept acquisition and transfer of learning. He distinguished three modes of experience - enactive, iconic and symbolic (see Figure 4). The **enactive** stage represents the learning content in ambiguous representations, in the form of easily understandable scenarios as perceptual and physical experiences. The **iconic** stage illustrates the learning content without deviating characteristics that are separate from the concept and links concrete and abstract instantiations as mutual references. The **symbolic** stage represents the learning content in generalizable and formal characteristics that are valid across all contexts (Jerome S. Bruner & Olson, 1973).

Spiral Curriculum

The transfer of learning content can be supported using Bruner's *Spiral Curriculum*, where each time a learner returns to the topic it should be learned at a deeper level and explore more complexity. The concreteness of the topic increasingly fades and becomes an abstract and generalized conceptualization (Concreteness Fading) (Goldstone & Son, 2005). The transfer of learning can be thought of as a process of abstraction and decontextualization and the ability to map the knowledge to new contexts (Hasselhorn & Gold, 2009).

The transfer of learning can be augmented by pre-structuring learning tools such as the "Advanced Organizer" (Ausubel, 1960). Ausubel highlighted that linking new material with existing knowledge (assimilation) is a significant challenge for learners, especially with discovery learning. Therefore, teachers should be involved in both the learning process and the delivery and preparation of the learning content.

The transfer of learning can further be supported by self-regulating strategies, including the reproduction of the learning content in one's own words, the creation of visual ideas, the search and active manipulation of examples, and the contradictions to existing knowledge (Schnotz, 2006).

Cognitive strategies, such as reductive processes (summarization, chunking), or metacognitive processes (planning, monitoring, evaluating) favor the elaboration from short-term memory into long-term memory (Traub, 2012).

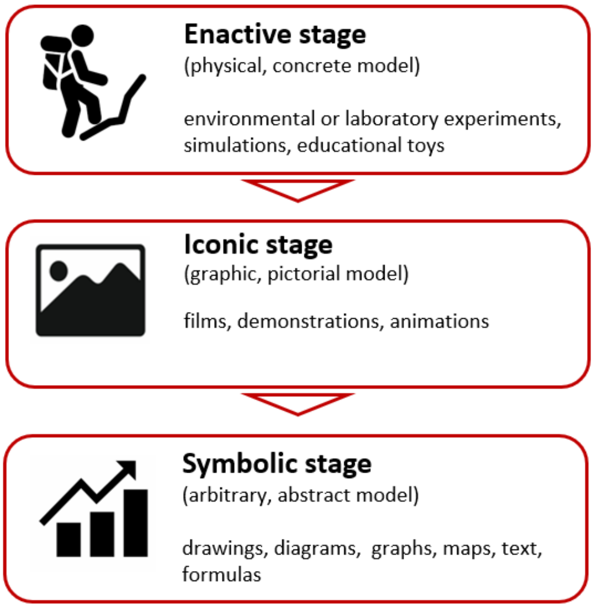


Figure 4 Modes of representations (Bruner 1966; Bruner and Olson 1973)

Constructivism is applied in diverse educational contexts as problem-based learning (PBL). Constructivism promotes critical thinking and problem-solving in authentic learning situations (Yew & Goh, 2016). Field-based learning with the environmental anchoring of constructivist knowledge acquisition, emphasizes the enactive stage regarding Bruner's Spiral Curriculum. Learners are placed in authentic learning settings, and problems are solved by applying Dewey's (1910) Learning by Doing approach (Lonergan & Andresen, 1988).

2.4.2.1 Problem-based learning

Problem-based learning according to Aebli's Padua scheme

Aebli (1983), a Swiss pedagogue, supported Piaget's theory of Cognitive Development (1954). With his thesis, "Thinking is internalized doing" (Aebli 1993), Aebli assumed that effective learning is achieved through *problem-based learning* (PBL), where the learning process is facilitated by the direct experience of solving an open-ended problem. Aebli (1983) used the *PADUA Scheme* (Problem Presentation, Structure, Work Through, Practice, Apply) to describe an educational concept in which project learning is structured with different learning phases. Aebli's approach was based on so-called "well-structured" problems (Simon, 1973), where the research question is given. This approach primarily served to deepen, review, and apply acquired knowledge and is comparable to the *ADDIE scheme* (Analysis, Design, Development, Implementation, and Evaluation) of Gagné (1985).

Ill-structured problem-based learning

The reverse of well-structured PBL are problem-first approaches or scientific problems, where the first goal in the initial situations is to create a research question and to find all the necessary information to develop a solution, called as "ill-structured" inquiry-based learning (Simon, 1973). Such activities do not test given abilities but ability to create new knowledge and skills. The collection of information, the perception of the problem, and the development of the solution is agile and form an iterative process. Students work in groups of four to six people and teachers act as moderators and can provide guidelines (scaffolding) on how to solve the problem. The assessment is performance-oriented (Stepien & Gallagher, 1993).

2.4.2.2 Field-based learning

In the 1980s, the term "field-based learning" evolved at the tertiary education level to cover every area within a subject that takes place outside of monitored classroom boundaries (Lonergan & Andresen, 1988). The term 'field' can be a 'green field', but as an overarching context, it covers a much broader perspective. During an excursion, the changed environment signals the release or 'letting go' of restrictions by the formal classroom environment (Keene, 1982). Free physical movement can create vibrant, unique, spontaneous, and unpredictable experiences for both teachers and students. As a result, field-based training can never be thoroughly planned (Kolb, 1984; Lonergan & Andresen, 1988). However, field-based learning is different from informal learning (cultural trips, regular school trips, etc.). Field-based learning is learning outside the classroom, combined with learning objectives (Lössner, 2011).

Stimulating the creation of knowledge, skills, and interest through authentic experiences

In contrast to the classroom, the achievements of the field experiences are often a qualitative and authentic form of the learning object:

- **Phenomena**: Field experiences allow the discovery of phenomena that occur in nature or natural environments in ways that go undetected when viewed superficially or unintentionally. These nature/natural environment-based phenomena can be observed with greater awareness and through untrained eyes and create a closer connection to the living world (von Niederhäusern et al., 2012).
- **Demystification**: The field can demystify acquired knowledge from the classroom or textbook. Exemplifying this is when floors are uplifted, smelled, and their texture felt, within their natural environment (Lonergan & Andresen, 1988).
- **Multiple stimuli**: The field activates human perception mechanisms in their entirety and multimodality. While in the

classroom, the human sensors of sight and sound are mainly activated, the field achieves a rich sensory experience with sound, feeling, taste, smell, and sight, with which the experience is linked twice, in semantic and episodic memory and thus avoids inert knowledge (Lonergan & Andresen, 1988).

- **Holism**: The field enables a holistic acquisition of knowledge. Demonstrating this is when large structures such as buildings, bridges, mountains, or lakes are considered in their entirety (Lonergan & Andresen, 1988).
- **Originality**: Students can collect raw data in an authentic environment by mapping, for instance, the vegetation of an area, finding fossils in a bed, revealing artifacts in an "excavation" or gathering peoples' opinions in a survey (Lonergan & Andresen, 1988).
- **Integration**: The field can make it possible to integrate individual parts or fragments of information that have been gained from lectures, texts, or experiences into a coherent whole. For example, when the physical and human geography aspects of a landscape are experienced (Lonergan & Andresen, 1988).

Explicit and implicit educational objectives of field-based education

Field-based learning affords the use of several explicit and implicit learning objectives (Keene, 1982; Lonergan & Andresen, 1988):

- **Acquisition of expertise**
  The place itself, as a natural phenomenon from entities of the learning object, can demonstrate structures or processes that are not accessible in other environments. This offers authentic learning opportunities to question, interpret, explore and model cognitive competences (Meek, Fitzgerald, Sharples, & Priestnall, 2013).
- **Acquisition of practical, intellectual, and methodological skills**
  The field-based environment's complexity allows for various methodologies of field work. These include: ambient sensing, data collection and analysis with scientific devices (as used in the scientific disciplines) (Meek et al., 2013); participant observation and detailed, unstructured or semi-structured interview procedures (as used in the social science disciplines) (E. Brown et al., 2010; R. G. Burgess, 2002; Meek et al., 2013); metacognitive techniques, such as assessment; and reasoning using techniques such as cognitive maps (Downs and Stea 1973; Ishikawa and Montello 2006).
- ***Use and consolidation of learning/learning transfer***
  The field-based environment can strengthen and consolidate learning content previously presented in the classroom or deepen it at a more sophisticated level (Lonergan & Andresen, 1988).

- ***Social awareness***
  The field-based environment can foster cooperative forms of learning and social awareness in an authentic context (Naismith et al., 2004). Special cooperative support is provided through the *Parrainage Method*, where older students support younger students in acquiring knowledge (Goldschmid, 1988).
- ***Development of attitudes and values (affective experiences)***
  The field-based environment can promote an attitude of appreciation, concern, and esteem for the physical, cultural, or social learning phenomena given the authenticity of the situation (E. Brown et al., 2010).

Field-based education allows for a variety of teaching strategies. Hemmer and Uphues (2009) and Stolz and Feiler (2018) classified field-based education according to the degree of learner's **self-regulation** or **learner's agency**. Thus, the self-regulation of the learner can be distributed between passive and regulated mainly by the teacher or external system, and active and learner regulated. Figure 5 describes the taxonomy of excursion according to the degree of learner's agency in four categories:

Instruction Tour

- The **Instruction Tour** describes a guided museum tour that is strongly influenced by others. The teacher presents the predefined learning content in a strongly instructivist way, without activating questions or problems. Learners show a high degree of passivity (e.g., company management).

Overview Excursion

- The **Overview Excursion** describes a problem-based overview excursion, where learners' agency is constrained. The mainly passive learners solve predefined problems interactively with the teacher and peers (e.g., hiking day or sightseeing).

Work Excursion

- The **Work Excursion** describes an action-oriented work excursion and shows a higher degree of agency and engagement. The predefined problems allow for open results within an action-oriented but rigid set of methods (e.g., field collection day or survey).

Inquiry Excursion

- The **Inquiry Excursion** describes a constructivist, entirely self-regulated working excursion with a free or only loosely defined scope of methods. The problems allow an active knowledge construction and open results (e.g., exploration task or trace search like a detective).

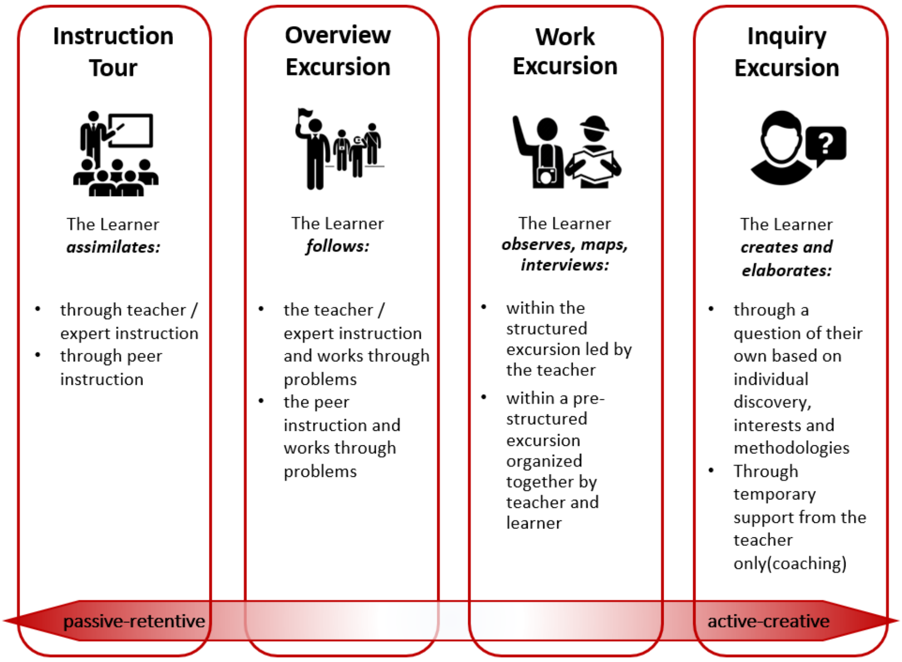


Figure 5 Taxonomy of excursions according to the degree of learner's agency (Hemmer and Uphues (2009) and Stolz and Feiler (2018)

Teaching preparation

A field trip lesson requires greater engagement on the part of the teacher than a classroom lesson (Lössner, 2011). As part of teaching preparation, the teacher must first define the type of excursion and secondly a requirement analysis, including the corresponding learning objectives. When establishing the objectives, the teacher should inspect the field, ideally at the same time of year as the lesson itself, to help ensure that the expected context is captured and test the crucial activities (Lonergan & Andresen, 1988). It is also necessary that the teacher constructs robust and weatherproof teaching materials and undertakes pre-planning and preparation in regards to the management of finances, transportation, instruments, and contingency plans concerning the weather forecast. (Lössner, 2011).

Pre-field trip preparatory lesson

Orion and Hofstein (1994) observed that learners demonstrated better learning performance on the field trip lesson when a pre-field trip preparatory lesson was conducted including a basic introduction of the material and instruments (cognitive preparation), field trip area and locations (geographic preparation), and detailed description such as length of the whole field trip, the duration of work at each learning stations, expected weather, and visuals of the route (psychological preparation).

Post-field trip activity

As Dewey and Boydston (1938) postulated with their Engagement Reflection Theory, an excursion should always end with a debriefing in which the results and experiences are shared and reviewed

(Lonergan & Andresen, 1988). This part of the teaching process allows for group discussions to address and resolve open issues, to correct remaining misconceptions, and to re-contextualize the experience into generalizable findings (Brooks, 2017).

2.4.3 Programming as self-regulated learning

In the 1970s, support for the principle of learning through constructivism grew. This coincided with the introduction of the first large-scale networked educational systems, including PLATO (Programmed Logic for Automatic Teaching Operations) and TICCIT (Time-shared, Interactive, Computer-Controlled Information Television) (Hagler & Marcy, 2000). Unfortunately, school technology had not kept pace with teaching pedagogies. The few schools that had computers in the 1970s used behavioristic computer-based learning programs with repetitive language exercises (Lee, 2000).

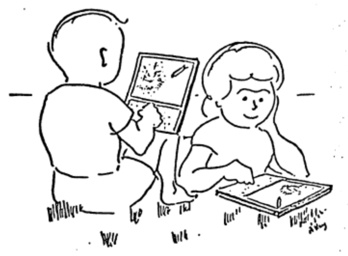
LOGO Programming for Children

Papert (1972), a former student of Piaget and who was inspired by Piaget's (1954) position that children build their intellectual structures, created the educational programming language LOGO. Papert argued that the computer must be a subversive instrument. Subsequently, he developed LOGO in a way that children could use it for self-regulated learning and for developing higher-thinking skills (Hill, 1994). Papert was a critic of the behaviorist-instructionist approach to computers. He noted that many computer-assisted learning environments still taught programmed learning, "which is based on behaviorist experiments with rats and pigeons" (A. C. Kay, 1972) (see Section 1.2.3). In The Children's Machine, Papert (1993 p.168) explained: "*Computers should serve children as instruments to work with and to think with, as the means to carry out projects, the source of concepts to think new ideas. The last thing in the world I want, or need is a drill and practice program telling me to do this sum next or spell that word! Why should we impose such a thing on children*?"

During the first four years of research, development, and teaching, LOGO provided children with a mathematical environment in which they could play with words and sentences. The most important feature of LOGO was the virtual turtle. The animal provided immediate visual feedback and allowed for debugging in graphical programming. Papert (1980) explained the reasoning for why LOGO was made for children and beginners in terms of its comparison to the programming language BASIC. For example, when the learning objective was to program a square house with a gable roof visually, BASIC and LOGO used different approaches. BASIC used the PLOT command (including the values of the coordinate tuple). LOGO sketched the shape of the house using the vectorbased approach Magnitude ("forward" plus value) and Direction ("right" or "left" plus value) to produce the crawling turtle drawing a line across the screen. BASIC implies the knowledge of spatial-analytical concepts of the user, such as the concept of the Euclidean coordinate system, while LOGO has the concept of successive modeling "try and error". BASIC needs instruction or prior-knowledge to cope with the task, while LOGO enables Dewey's (1910) approach of Learning by Doing to learn rules and concepts, from the beginning, in a self-regulated way. Papert (1980) perceived Constructivism as an ideal approach for children to learn with confidence and in a sustainable way with confidence. Kay (1972) described Papert's approach as CAI, meaning the acronym as "Computer Aided Intuition" or "Computer Aided Inspiration." Papert, meanwhile, defined his alternative approach to constructivist learning as Constructionism because learners actively construct new knowledge with interactive models (Naismith et al., 2004). Through coding procedures and debugging, Papert recognized valuable skills and believed that these fostered problem-based learning and critical thinking (Papert, 1980). This pedagogical change shifted the role of teachers so that they became a kind of coach or "debugger" (Papert, 1993). In 1989, Papert's constructivist teaching approach saw him awarded the title of "LEGO Professor of Learning Research" (Hill, 1994).

Dynabook, the first mobile computer

The period of Paper's research, the 1970s, schools were using CAI, but, as desktop computers were limited to computer rooms, they, therefore, could not be used in normal teaching situations (Crompton, 2013). This shortcoming inspired Kay (1972) to invent *Dynabook*. Dynabook was the first mobile multimedia computer that "would" allow children to explore, create, and share dynamic games and simulations with technology. Kay built his prototype in 1968 and called it *Personal Computer (PC)*. Its system requirements, and an excerpt of a sketch about the ideal way of use, are provided in Table 2. In "A Personal Computer for Children of all Ages" (Kay 1972, p.1) describes the PC as follows: "*lt can be like a piano: (a product of technology, yes), but one which can be a tool, a toy, a medium of expression, a source of unending pleasure and delight…and, as with most gadgets in unenlightened hands, a terrible drudge!*"



Zap! With a beautiful flash and appropriate noise, Jimmy's spaceship disintegrated; Beth had won Spacewar again. The nine-year-olds were lying on the grass of a park near their home, their DynaBooks hooked together to allow each of them a viewscreen into the space world where Beth's ship was now floating triumphantly alone.

- Carry anywhere device
- Not larger than a notebook
- Weighs less than four pounds
- Flat-panel and display for 4000 characters
- Dynamic graphics
- Removable local file storage that stores at least 500 book pages, or several hours of voice and music
- High bandwidth communication of 300Kbits /sec
- Connection to wireless network Arpanet
- Input via keyboard
- Rechargeable batteries
- Costs under $500

Table 2 The Dynabook - the first mobile computer - by Kay (1972)

The Dynabook was intended to solve the issues surrounding Dewey's (1910), Piaget's (1954), Papert's (1972) approaches to the way children learn (A. C. Kay, 1972). The Dynabook, for example, provided, for the first time, a digital, personal, and interactive learning environment with the concept of collaborative and gamified learning. As a programming language, Kay used LOGO via the timesharing system for rendering dynamic simulation. The Dynabook allowed learning anytime and anywhere, and it is this that had ensured its enduring success in terms of research in mobile learning (Sharples, Arnedillo-Sánchez, Milrad, & Vavoula, 2009). The Dynabook project had far-reaching consequences for the development of the networked personal computer regarding the system requirements (see Table 2). Unfortunately, early innovations at that time were desktop-based, and the researchers at Dynabook were not only over-optimistic about the progress of technology development but also about their goal of equipping learners and schools with mobile devices (Sharples, 2002).

Motorola DynaTAC 8000X, the first mobile phone

In 1973, the first mobile phone, the Motorola DynaTAC 8000X, was launched. It was the first commercially available mobile phone that was small enough to be easily carried (Crompton, 2013). Dynabook and DynaTAC 8000X paved the way for future mobile learning devices.

2.4.4 Social constructivist teaching strategies

Piaget (1954) believed that children learn through active engagement with their environment, and through curiosity. The child educates himself/herself through a constructivist approach. Similarly, Vygotsky (1978), one of the founders of social constructivism or co-constructivism, posited that social interaction is an essential factor in the construction of knowledge. Both theorists held that children learn to understand the world by interacting with others and negotiating meanings among themselves (Neubert et al., 2001).

Various learning activities embrace the learning paradigm of *Social Constructivism* as situated and collaborative learning, which promotes interpersonal skills. Such skills include persuasion, active listening, negotiation, mentoring, and social perspective in authentic learning situations. Teachers can implement these activities in situated and collaborative learning strategies.

2.4.4.1 Situated learning

Situated Learning by Lave and Wenger

Lave (1988) claimed that perception, knowledge, and action are created together and are not, therefore, separate processes. She postulated the theory of situated learning, which emphasizes the social anchoring of individual learning by sharing and negotiating knowledge or opinions. Lave's *Situated Learning Theory* draws from Piaget's (1954) insight (knowledge is a result of direct experience of the environment), Vygotsky's (1978) conviction (knowledge is based on collaborative learning), and Aebli's (1983) work (the value of problem-solving learning). Lave credited situated learning spaces as creating authentic learning environments. Within these environments, the learner is exposed to different contexts (social, natural, medial, and varying places) and is engaged in multiple levels of proficiency (novice, advanced beginner, competent, proficient, expert). Articulation and reflection are of particular importance in terms of increasing self-regulation. Focusing on learning progress instead of mistakes promotes intrinsic motivation, self-responsibility and self-concept (Woolfolk Hoy & Schönpflug, 2008).

Lave viewed memory as *working memory* in the process of problem-solving. It does not, she claimed, require any factual knowledge of long-term memory. Long-term memory has the function of identity, attitude, and self-concept (see Lave (1988), Figure 2, page 16). The semantic memory represents a network of personal facts and is not exclusively but often interwoven with episodic memory in the context of experienced personal events (L. Anderson et al., 2001). This interdependence links factual knowledge through emotions and gives understanding to an ethical dimension. This interdependence can also overcome inert knowledge. Skills are stored implicitly and procedurally and are only partially conscious.

Process of "Legitimate peripheral participation" by Lave and Wenger

Lave (1988) was critical of formal classroom learning. She believed the classroom environment was removed from real phenomena and that learning best occurs in everyday activities that are unintentional, informal, and involve real-life social interaction. Lave and Wenger (1991) articulated their ideal situated learning argument through their Legitimate Peripheral Participation model. The novice learner integrates into a "community of practice" of experienced members who embody certain beliefs and behaviors to be acquired. When the novice moves from the periphery of a community to its center, he/she becomes more active and involved in the culture, and ultimately assumes the role of "expert". When the learner reaches this height, he/she has completed the learning transfer (Lave, 1988). Anderson et al. (1996) contested Lave's hypothesis, using mathematics as an example, arguing that active learning is possible in abstract contexts without social interaction.

Teaching situated learning refers to the creation of authentic learning environments to allow learners to solve problems practically in communities (Gerstenmaier & Mandl, 2001). The teacher should respect the learners' prior knowledge and apply adaptive teaching methods based on learning progress, work structure, intensity, and attitude. The tasks should be conducted with limited structure, and the focus should be on understanding, recognizing, and discovering. Mistakes should be used as a diagnostic tool to advise learners (Gerstenmaier & Mandl, 2001). The teacher acts passively, seeking to broaden the scope of the situation. If necessary, the teacher provides successive levels of temporary support to help students achieve a higher level of understanding, skill acquisition, and self-control (Neubert et al., 2001). The assessment should ideally focus on the study of productive learning environments and their characteristics (authenticity) (Jerome Seymour Bruner, 1990), the collaborative learning culture (A. L. Brown, 1997), and/or cognitive apprenticeship (A. Collins et al., 1988).

Cognitive Apprenticeship

Situated learning forms the basis of *Cognitive Apprenticeship* (A. Collins et al., 1988) in the sense that it establishes a master-apprentice relationship. Cognitive Apprenticeship is intended to make cognitive processes visible to the novice learner. The learner should be able to acquire, develop, and use cognitive theories in authentic and professional environments (J. S. Brown, Collins, & Duguid, 1989) by four stages:

(1) **Modeling**: The teacher demonstrates the procedure.

(2) **Scaffolding**: The teacher initially helps students to reach higher levels of comprehension and skill acquisition that they would not be able to achieve without assistance.

(3) **Fading out**: With the increase of the learner's competence, the teacher incrementally removes the supportive strategies, when the strategies are no longer needed.

(4) **Coaching**: The teacher gradually shifts the responsibility for the learning process to the student. This fosters independent learning and allows for the observation of the learning process from a distance.

Gerstenmaier and Mandl (2001) recognized vital features in the application of a successful cognitive apprenticeship strategy. These included two advantages. First, learning is an active and constructivist process, oriented at the knowledge shared in the social learning group, and second, learning takes place in multiple, partly stimulating and restrictive contexts, in the process of peripheral participation with increasing expertise towards central participation.

2.4.4.2 Social learning

Lave (1988) and Vygotsky's (1978) learning approach involves teamwork in context, by which learners construct knowledge in cooperation with peers and teachers to achieve a common goal or to complete a task. Social learning is distinguished in the way learners work together, namely between "collaborative learning" and "cooperative learning" (Brüning & Saum 2011):

Social learning through collaboration or cooperation

- **Collaborative learning** describes the shared processing of a task in which the goal is to find a consensus or common solution through negotiation. Collaborative learning has an effect size of d = 0.34 (Hattie 2013).
- **Cooperative learning** describes a division of tasks, ensuring that each group member deals more closely with a specific topic. The results are then compiled and put together as a whole. With an effect size of d = 0.40, cooperative learning is at the hinge point to the zone of desired effect sizes (d > 0.40) (Hattie, 2013).

Social learning takes careful planning and structure to work well and includes over 100 strategies for a variety of learning objectives. It includes activities for: group function, accountability, knowledge and comprehension, analysis, synthesis and evaluation, reflection, activities to complement projects, to gain feedback and to complete a course, etc. (Macpherson, 2007). A key pair of principles is positive interdependence and group responsibility (Roschelle, Zaner, & Patton, 2019). Positive interdependence implies that the assigned task requires work for each learner, otherwise it will not be completed. Learners need each other to succeed. Everyone is responsible for the learning of both the group and themselves (Brüning & Saum, 2011). Group responsibility means that the result or grade of the strongest learner in a group depends on the result of the weakest learner in the group. Therefore, the individual responsibility of each group member matters to contribute to the work. Both levels of responsibility require careful teaching. This is achieved by measuring and reporting the performance of individual members and through the provision of rewards at the team level. Two successful teaching strategies align the basic principle of cooperative learning:

Think - Pair – Share – Technique

The **Think - Pair - Share - Technique** (Lyman, 1981) consists of three work phases. The first phase is individual development (construction). The learner can work on the topic individually by brainstorming. The second phase involves exchange in the group (1st co-construction of a common solution). The learner joins a group colleague and discusses pairwise his/her idea(s) and then listens to those of his/her partner's. In the third phase, findings are presented to the plenum (2nd co-construction by the participants). After the pairing dialogue, the learner presents his/her results and receives feedback from the whole group.

Jigsaw I

The **Jigsaw I** method (Aronson, 1978) is a sophisticated refinement of the Think - Pair - Share - Technique, known as the *Puzzle Method*. Class members are divided into class groups. Each class group works on the overall theme, but each member works individually on a different part to obtain specific expertise. Then, the "experts" meet to compare their results. The experts then return to their class group to present their area of expertise to other group members. Finally, the overall topic is discussed with all group members. The first step is to develop the material independently. In the expert groups, quality differences in the individual tasks are balanced out. In the third phase, the group members must listen to the presenter, encourage, and support him/her. This prevents the other group members from being perceived as competitors. The group puzzle method with d=1.2 is, according to Hattie (2013), one of the most successful teaching methods(Hattie, 2013).

Cooperative learning in situated mobile learning activities

Cooperative learning is not only popular in the classroom (Slavin, 2010) but also in situated mobile learning activities to improve learning outcomes (Huang et al., 2014). Collaborative learning is one of five key affordances of mobile phones (Klopfer, Squire, & Jenkins, 2002), which the following two examples show:

Mattila and Fordell (2005) used a collaborative learning design with primary school children to teach recycling and sustainability. Using mobile phones, and working in pairs, the children analyzed different topics at a recycling center and collected observations via GPS tagged photos, videos, and voice annotations. Questions regarding the center's smell and large population of birds were analyzed and discussed on site. Upon returning to the classroom, individual groups presented their results and experiences, and then the class as a whole reflected on and discussed these.

Huang et al. (2014) undertook research to improve learning outcomes with jigsaw-based cooperative learning methods when used in conjunction with mobile phones. Students observed fish and upstream, midstream, and downstream river ecologies to increase their understanding of the various water regions in Taiwan. Groups consisted of high-, medium-, and low-achieving students, and Google+ was used to discuss and exchange opinions. The results revealed that using jigsaw-based cooperative learning for situated ecological instruction is achieves more engagement than individual self-regulated learning.

The two research projects described above illustrate that the learning outcome of situational learning activities can transform goal-oriented, purely cognitive classroom activities into social learning experiences. Furthermore, both projects demonstrate that a situational learning environment improves cognitive goals (knowledge and skills) and affective goals (self-reliance, cooperativity, and communicative skills) (Gillies, 2016).

2.4.5 Learning management systems for collaborative learning

The 1980s witnessed a marked interest in the principle of learning through co-construction. Following a decade of behavioristic computer-based learning programs, the 1980s saw the revival of computer-assisted instruction (CAI) (Niegemann et al., 2008). During this time, multimedia personal computers diversified due to strong demand within the tertiary sector. This development led to the need to train employees in computer skills and to develop computer-based training (CBT) programs. Consequently, the function of computers shifted from an exclusive presentation tool to an interactive learning environment.

In the 1990s, learning platforms with open content as Open Educational Resources (OER) and with community-restricted content as learning management systems became popular. This was a consequence of the gradual emergence of the internet, the increasing use of computer synchronous or asynchronous, web-based, and distance learning. It was also a consequence of the pedagogical shift from CAI to CBT. The focus of CBT was on effectiveness and efficiency including aspects of self-regulated learning, thus pushing the emergence of management systems (Niegemann et al., 2008).

Learning management systems as integrated systems for e-learning

A Learning Management System (LMS) is an integrated software application on local or cloud-based servers for conducting and managing e-learning courses for educational and training purposes. According to Baumgartner et al. (2002), the definition of an LMS is based on the existence of five functional areas:

- **Teaching** tools for presentation and distribution of content.
- **Learning** tools for accessing the content and creating tasks and exercises.
- **Tracking** tools for evaluation and assessment of the learning progress.
- **Communication** tools for exchange between learners and teachers.
- **Administration** tools for supervising.

Since 2000, LMS has offered various multimedia content, including audio and video, course structures and exchange, and backup possibilities of documents (Niegemann et al., 2008). This content allows students greater independence and agility in the management of their personal learning environment and, in the case of collaborative tools, social learning activities (Dalsgaard, 2006).

Cooperative and social technologies

In 2005, Anderson (2005) introduced educational, social software through distance learning. He defined educational social software "as networked tools that support and encourage the individual to learn together while maintaining individual control over his time, space, presence, activity, identity and relationship" (Anderson, 2005, p. 4). In terms of system requirements for effective cooperative learning, Anderson (2005), Lämmle (2009), and Niegemann et al. (2008) agreed that communication tools, such as social publishing, discussion forums, wikis, social networks (chat, messenger), e-portfolios, audio and video conferencing, and space, enable a personal learning environment (PLE) to store personal content. Zurita and Nussbaum (2004) outlined the concept of a collaborative environment for mobile phones. Their system monitors weaknesses in coordination, communication, material organization, interactivity, and lack of mobility in real-time directly from mobile phones.

2.4.6 Relevance to this dissertation

The concept of constructivism assumes that learning always starts with an action, according to Bruner's (1961) theory, and that knowledge construction takes place through self-perception and personal experiences that depend on context, person, and social situation (Jonassen, 1992). LBML, as an approach, contributes to constructivism through connecting the natural environment as an open-air laboratory with ubiquitous access to digital information using mobile technologies to deliver learning in a way that is authentic, situated, problem-oriented, and personalized. However, LBML teaching designs can range from teacher-centered instruction, such as tourism-like guided field trips, to learner-centered open inquiries with ill-structured problem-based learning activities. Therefore, research question **RQ1** is about how an LBML system with GIS and multimedia capabilities can be designed in such a way that both structured and open inquiries can be given. In open inquiries, learners can initiate the research question, choose the method for solving the problem, and regulate the solution. Tan et al. (2018) formulated learners' autonomy levels during an outdoor inquiry by examining empirical studies using a literature review. The results of the empirical studies of Chapters 3 and 4 will answer research question **RQ2**—how teachers design inquiry-based activities—and research question **RQ3**—how learners perceive the style of inquiry and contribute to the research on inquiry in mobile learning.

The concept of social constructivism assumes that learning occurs primarily in social and situated environments, where knowledge is collectively co-constructed. The cognitive apprenticeship model suggests that learners are positioned in authentic places and that teachers or peers act as coaches who demonstrate a procedure before gradually shifting responsibility to the students. The case studies of Chapter 3 include the apprenticeship model combined with social learning activities, both face-to-face and online, to foster learner agency through positive interdependence in a group and group accountability. The teaching designs (**RQ2**) refer to the social aspects of learning and how students in higher education perceive social learning **(RQ3)** and discuss its educational aspects, including the advantages and disadvantages of oral and digital conversation.

2.5 Knowledge contextualizing and location-aware computing

In the early 1980s, shared desktop computers were placed in specific environments and connected to a fixed number of other computers. The physical installation of desktop computers determined the organization and behavior of how people collaborated, communicated, and solved problems at desks.

In the late 1980s, the era of personalized technologies began. The previous trend of shared desktop computers moved to laptops and portable personal computers. This eliminated the need for employees to sit at specific desks on which their computer sat. Portable computers made it possible to work on the move, anytime, anywhere.

The Grid Compass was the first battery-free portable computer used by the US National Aeronautics and Space Administration (NASA). It was built for the Space Shuttle program in 1979/80. In 1981, Osborne 1 was considered the world's first truly portable laptop computer. The 5-inch display computer was equipped with a battery and was designed for mass production. The portable computer weighed over 10kg (Bird, 1985). These commercial, portable computers were far from the Dynabook concept (A. Kay & Goldberg, 1977) in terms of technology and were primarily used for business purposes. During this same period, the telephone industry evolved. Among the first personal mobile phones was the 1983 TRS-80 Pocket Computer by Radio Shack and the 1984 PB-700 Handheld Computer by Casio (Crompton 2013, p.9 Table1.2).

Context-aware computing

With the increasing mobility of computer hardware - increasingly also for non-business purposes - computing disseminated in a variety of situations and locations (Baecker, 2007). Schilit et al. (1994) introduced a collection of mobile and stationary computers that communicated and collaborated under the name *Mobile Distributed Computing System*. As context-aware computing, they referred to the concept of sensing and reacting to dynamic environments and activities, mobile computing, and wireless communication, information, and resources of stationary computers, became accessible anywhere. The term "context" is defined as "*any information that can be used to characterize the situation of an entity*" (Dey 2001, p.5). A person's context encompasses all the characteristics of the person's physical (where you are and what resources are nearby), social (who you are with), physiological, or emotional (how you are) environment location (Steiniger et al., 2006). Schilit et al. (1994) added technical aspects of the context definition, such as communication bandwidth, network connectivity, speed of the mobile user, and weather conditions.

2.5.1 Location-aware computing with GPS

Context-aware computing that senses a particular context or embeds contextual information of locations is described as location-aware computing (Duckham & Kulik, 2006). Location-aware computing includes two categories of positioning systems: active and passive systems. Active positioning systems rely on the establishment of beacons to operate, such as Wi-Fi signal triangulation, infrared proximity sensors, and Global Positioning System (GPS). No transmitters are required for passive positioning systems, including inertial tracking, scene analysis and computer vision, and audio-based positioning and radio signal profiles (Duckham & Kulik, 2006). These systems vary widely in their accuracy and precision characteristics, which have implications for location privacy. For example, a positioning system that locates an individual to a precision of 200m generates less information about location (and so can potentially be less invasive of location privacy) than a positioning system that locates the individual to a precision of 2m.

Global Positioning System

In outdoor applications, GPS (owned by the United States of America Government) is the best-known positioning system. GPS, officially 'Navigational Satellite Timing and Ranging - Global Positioning System' (NAVSTAR GPS), is based on the time and known position of GPS satellites (Kaplan & Hegarty, 2005). Each GPS satellite is equipped with one or more atomic clocks, which are synchronized with each other and ground clocks. Any deviation from the time on the ground is corrected daily.

Figure 6 depicts the schematic illustration of GPS. Each GPS satellite continuously transmits a radio signal that contains the current time and data about its positioning. Since the speed of the radio waves is constant and independent of the satellite speed, the time delay between the transmission of a signal by the satellite, and the reception by the receiver, is proportional to the distance from the satellite to the receiver. A GPS receiver monitors several satellites and calculates the exact position of the receiver from the different signal times, and requires at least four satellites in its field of vision to calculate the latitude, longitude, and altitude of the receiver's position (Kaplan & Hegarty, 2005). For military purposes, the U.S. government has intentionally degraded positioning accuracy for civilian users with selective availability (SA). In the 1990s, SA was reduced to about 50-60 m positioning accuracy (Cornelius, Sear, Carver, & Heywood, 1994).

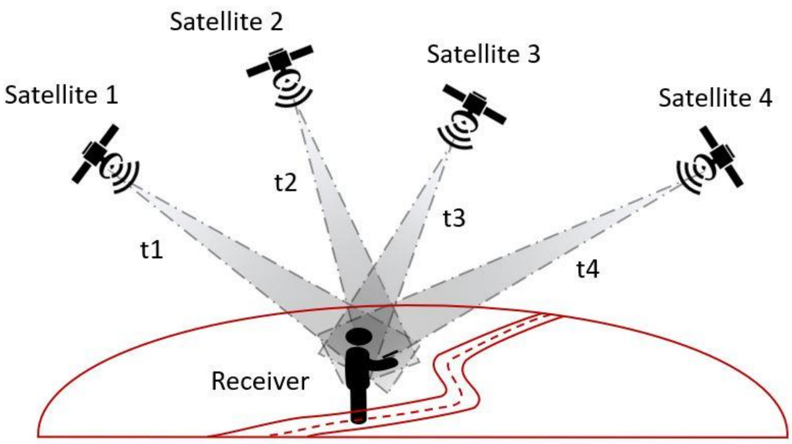


Figure 6 Global Positioning System (GPS) with the GPS receiver on the ground measuring the time delay of signals arriving from a minimum of four satellites to calculate the receiver's position

At the same time, two alternative surveying techniques were available for calculating a position, the so-called position fix: Differential GPS with two receivers and Wide Area Augmentation System (WAAS)-capable GPS receivers using satellites and ground stations. Both techniques achieved submeter accuracy using GPS signal corrections (Ashkenazi & Cleasby, 1993). These measurement methods not only required several expensive devices but also needed longer waiting times per measurement (see Cornelius et al. 1994). Several tests in practical use demonstrated that these methods were unsuitable for both mobile civil society and the transport industry in terms of real-time positioning.

Discontinuation of selective availability

On May 1st, 2000, U.S. President Bill Clinton announced the discontinuation of selective availability of the Global Positioning System (GPS)[6]. The decision was a milestone for the civil and business society and has opened the way to an avalanche of novel services, new typologies of users, advanced integration architectures to both existing systems and newly conceived ones (Prasad & Ruggieri, 2005). With client-based positioning systems, such as small, portable, civilian GPS receivers, locations could be determined independently of time and place with an accuracy in the single-digit meter range (Adrados et al., 2002; Hazas, Scott, & Krumm, 2004). In terms of efficiency, however, standalone GPS often requires a long start time and high power consumption due to communication with several satellites using a 50 bit/s data-stream (Ma, 2014). This limitation explains why manufacturers of current mobile phones not only base their location recording on GPS but also network-based and network-assisted positioning systems.

[6] https://clintonwhitehouse4.archives.gov/WH/New/html/20000501_2.html (28.11.2019)

Network-based positioning systems of mobile phones use Cell-ID positioning with Cell Global Identity (CGI) to calculate the position of the device. Network-based positioning systems use Assisted GPS (A-GPS)), which combines network-based CGI positioning with GPS to increase the speed of GPS positioning (Duckham & Kulik, 2006). Pei et al. (2009) evaluated ubiquitous positioning technologies on smartphones, including integrated GPS, Bluetooth GPS, A-GPS, network-based, multisensory, and Wireless Local Area Network (WLAN). The results for outdoor use were that Radio-Frequency Identification (RFID) and Bluetooth showed particular limitations, while A-GPS and integrated GPS revealed better results. Van der Spek et al. (2009) confirmed these results in an extensive review of related work. With the increase in Wi-Fi access points, Wi-Fi positioning, which combines Wi-Fi access points, is another important network-based positioning system for determining location in populated areas with mobile phones (Ma, 2014).

2.5.2 Convergence between learning and technology

In the 1990s, the shift from CAI with multimedia learning programs to the use of Tim Berners-Lee's web browser initiated the first decade of the learner-centered movement in schools (Crompton, 2013). At the same time, mobile phones became lighter, flexible, and adaptable, and computers began to generate identity. Subsequently, a "mobile phone culture" emerged (Goggin, 2006), which gave new meaning to the concept of situated learning (Lave & Wenger, 1991).

Personal digital assistants as the first mobile computers for schools

The release of digital cameras and the Palm Pilot's Personal Digital Assistants (PDAs) was an exciting development for schools (Sharples, 2002). It inspired first attempts to describe a new pedagogy as so-called mobile learning with a focus on technology. It was defined as "e-learning through mobile computational devices: Palms, Windows CE machines, even your digital cell phone" by Quinn (2000, p.1). Furthermore, PDAs introduced an era in which mobile communication and handheld computers converged, and this offered the possibility to learn anywhere, anytime. This mobile capability of computers inspired Sharples et al.'s (2002) attempt to resume the Dynabook project concept (see Section 2.4.3). Through the student project, Handheld Learning Resource (HandLeR), Sharples et al. (2002) specified the key requirements of mobile technology that support personal learning environments (PLE) for Lifelong Learning:

- **Highly portable**: available wherever learning is needed.
- **Personalized**: adapted to the learner's skills and knowledge.
- **Seamless**: situations are captured, and knowledge is retrieved.
- **Available anywhere**: seamless connection with teachers and peers.
- **Adaptable**: adapted to the context of learning and the learner's abilities.
- **Persistent**: lifelong access to resources despite technology change.
- **Useful**: suitable for everyday use for communication, work, and learning.
- **Easy to use**: manageable by persons without prior technological knowledge.

Sharples et al. (2002) evaluated PDAs in a field trial in central Birmingham (UK). Student participants were divided into two groups of three. They were required to use HandLeR screens to explore local canals and their boats, answer two questions, and return to the classroom with evidence of their artifacts. HandLeR allowed them to navigate the channels using topographic maps and to visualize findings on the "HandLeR mind map" as sketch notes. The students were encouraged to communicate via the mobile phone connection and to gather information through note-taking and voice recording. The evaluation showed that poor performance was the main limitation of the student's dislike of the PDA. In response to the question about what computers should do in the future, students most said that computers should enable presentations, conversations with peers and experts, and allows for the management of personal learning projects. The overall results demonstrated that further experimentation should be delayed until the technology has developed to the point where it is easy and intuitive to use (Sharples et al., 2002).

Mobile learning as a new independent field of research in the 2000s

At the same time, as the project HandLeR, mobile learning increasingly became recognized as a new independent research field. The European Commission, for example, supported two major mobile learning projects within the Information Society Technologies (IST) program - m-learning in 2001 and MOBIlearn in 2002 (Naismith & Corlett, 2006). The main objectives of m-learning projects were to explore prototype products and services that provide information and learning experiences on context-aware computers. For instance, Oppermann and Specht (2000) developed and evaluated with a context-sensitive nomadic exhibition guide that considered the location context for information selection and presentation. Another example, the MOBIlearn project of Lonsdale et al. (2004) aimed to explore museum artifacts by context-sensitive approaches using ultrasonic positioning in conjunction with Radio Frequency Identification (RFID) tags, which measured the history of learners' movements.

2007: Apple launched the iPhone

In the early 2000s, research studies with prototype technologies and participants with limited experience with mobile technologies characterized mobile learning. Therefore, 2007 was a significant year for both the mobile society and mobile learning research as networked, mobile technologies such as smartphones and tablets became popular and generated a high level of public interest. The 2007 release of the iPhone OS 1 smartphone was a commercially groundbreaking event. Apple announced iPhone OS 1 with Steve Jobs' legendary speech "Apple Reinvents the Phone with iPhone" on January 9, 2007[7]. The iPhone included applications such as visual call lists, multi-touch gestures, email, web browser, text messaging, a music and video player app, and a map. It also included basic applications for contacts, calendar, photos, stocks, weather, clock, calculator, notes, and personalization applications.

The evolving interest in digital communication led to the growing dialectical relationship between mobile technology and learning. In 2007, Sharples et al. (2007) observed a mutually productive convergence between technological influences on culture and contemporary educational theories and practices. If a technological system enables distinct forms of communication, learners begin to adapt their communication and learning activities accordingly (Sharples et al., 2005). In response to observations in explorative research, Sharples et al. (2007) created the following theory of learning for the mobile age (see Table 3):

Convergence between learning and technology

New Learning	New Technology
Personalised	Personal
Learner centered	User centered
Situated	Mobile
Collaborative	Networked
Ubiquitious	Ubiquitious
Lifelong	Durable

Table 3 Convergence between learning and technology (Sharples et al., 2007)

While effective learning is considered in personalized and learner-centered activities, it is new digital technologies that offer customized services such as music playlists and digital calendars. When mobile users have problems to solve or knowledge to share, networked devices enable exchange and collaboration. The emergence of synchronous social communications, such as instant messaging platforms of MySpace,

7 https://www.apple.com/newsroom/2007/01/09Apple-Reinvents-the-Phone-with-iPhone/ (28.11.2019)

Facebook, LinkedIn, Skype, and Google+ across the globe, led Crompton (2013) to a new definition of mobile learning. It now included social interactivity in addition to pedagogy, technology, and contextuality:

Definition of mobile learning

"*Learning across multiple contexts, through social and content interactions, using personal electronic devices*" (Crompton 2013, p. 4).

With the growing availability of push & pull technology through embedded physical sensors that triggered notifications and new messages for interaction and social exchange based on physical and temporal context, the convergence of the mobile phone and the user continued to grow. The push & pull technology shows that learning mediated by tools both constrain and support learners in their goals of constructing knowledge and skills (Sharples et al., 2007). The dialectical relationship between humans and technology, which is built up during learning processes with mobile devices, is described in the *Task Model* for mobile learning (Sharples et al., 2007) through an adapted version of Engeström's *Activity theo*ry (1987). The relationship is understood as the influences and effects of mobile devices on humans and vice versa. The framework task model analyses the learning process from two perspectives: a *technological* view of human-computer interaction, physical context, and digital communication; and a *human* perspective of social conventions, community, conversation, and division of labor. These two perspectives work together to promote a co-evolution of learning and technology.

2.5.3 Location-based mobile learning in and about locations

Learning across multiple contexts assumes that learning as an activity, transcends the classroom into the realm of informal learning, and learners are physically continuously on the move (Crompton, 2013). Learning here is understood not merely in terms of physical mobility, but in the way that learning goals and activity are experienced (enactive, iconic, or symbolic) (Jerome S. Bruner & Olson, 1973), and how knowledge is constructed (multimedia channels) (Mayer, 2005); in other words, how learners solve problems in social situations (Lave & Wenger, 1991).

Location-based mobile learning – the pedagogy of place-based education and geolearning

Connecting personal experiences in specific and real-world places with the learning content of the location-based mapping tools means being cognizant of, and having a feeling for, the immediate environment, described as placed-based education (Sobel, 2004) or the pedagogy of geolearning (Sharples, 2019). Place is a term from the discipline of geography that began to be developed in the 1950s and became a major concept in the discipline during the late 1970s (Cresswell, 2004). As a result, a place has many definitions, from the simple "a meaningful location" or "space infused with human meaning" to the more complex "an area with unique physical and human characteristics and actions that are connected to other places" (Jordan et al., 1998). Moreover, a place can be better understood by examining its opposite: the concept of space (Cresswell, 2004). Agnew (1987) distinguished three key components of place: such as (1) location, (2) locale, and (3) sense of place.

The concept of place

The first component of place – location - is the position of a particular point on the surface of the Earth. A location may be described as an absolute location, meaning the exact location of an object on Earth, or as a relative location, indicating the location of an object relative to another (Resor, 2010). Stahl and Heckmann (2004) described the difference absolute/relative of physical locations into quantitative (geometric) location models and qualitative (symbolic) location models. Quantitative location models refer to coordinates with two, two and a half, or three dimensions such as geographic coordinate system. They are objective and rarely contested and used, for instance, in navigation systems to determine the route between two absolute positions. Qualitative models refer to spatial information as context such as buildings, rooms, streets, countries, etc. that depict a mutually nested relationship and are used to give a better idea of its location.

The second component of place – locale - is the physical and material setting for social relations between people, within which people conduct their lives as individuals. For instance, for home, the place settings consist of actual objects—roads, buildings, trees, walls, furniture, doors, or pictures on the wall (Resor, 2010).

Locale-specific activities or tasks such as inquiry, data collection, recording, analysis, and evaluation, increase the awareness and attitudes towards the learning content and allow to perceive the phenomena at that moment, and to question how it looked in the past, and to conclude how it might change in the future (Brown et al., 2010).

The third component of place - a sense of place - describes the subjective and emotional attribute someone attaches to an area based on their experiences. Place can be applied at any scale and does not necessarily have to be fixed in either time or space. Additionally, place can change over time as its physical setting and cultures are influenced by new ideas or technologies (Resor, 2010). Regarding discovery learning, the learners' context embraces not only the location and located phenomena, but also interactions between the peer learners and material on the multimedia guide, the conversation of the peers, their prior knowledge of the phenomena and its natural surrounding and its personal, cultural and historical meaning, the wayfinding to arrive at the phenomena, and known and unknown people around them. The sense of place is continually unfolding as they move, talk, and engage with the surroundings of the museum to create personal and shared meaning (Brown et al., 2010).

In this dissertation, the overarching context is that of the place-based education, and the research topic is thus the field of place-based education, context-aware learning, geolearning summarized and simplified as location-based mobile learning.

2.5.3.1 Learning about locations

When learning about a location, the aim is to understand the characteristics of the phenomena being studied, to observe evidence of the phenomena's function or processes, and to determine how it has developed and can continue to develop in the future (Sharples, 2019). Supportive pedagogies of learning about a location are traditionally in fields such as geography, architecture, history, and environmental sciences. These fields all consist of learning objectives, which can be applied to or experienced with visible or invisible phenomena, that are tangible and localizable as geospatial object. Visible features include, among other things, geomorphological rock formations or settlement structures and invisible features, such as air pollution, solar radiation, property prices. Or a mix of both, gentrification, as presented in Section 1.1.1, includes both the visible and the invisible as well as the component of time. In real-world settings, the above-examples have their unique contextual characteristics regarding space and time. They can be investigated for underlying theories, rules, or patterns through inquiry-based activities such as mapping and documentation, analysis, and comparisons with peer phenomena using appropriate instruments. They can also be reviewed and discussed with peers, the teacher, or local people associated with the phenomena. Apart from the Handheld Learning Resource (HandLeR) project (Sharples et al., 2002), other researchers have undertaken studies on geolearning about locations.

In Ambient Woods (Rogers et al., 2004) research study, primary school children participated in an outdoor science education lesson and explored pairwise the woodland environment with augmented reality technology. The physical environment was a blend of contextually relevant, mobile information and resources, such as wood noise and wood. Within this environment, learners were able to integrate their skills and prior knowledge through a dialectic process of reflecting and acting.

So et al.'s (2009) study investigated the behavior of primary school students who were required to analyze and evaluate landmarks within Singapore's Chinatown using interactive maps on mobile phones. The project enabled learners to construct factual knowledge through constructivist learning activities, such as speaking with residents.

Zurita and Baloian's (2015) study examined high school geology students who conducted field measurements in small groups using a GPS application that contained interactive maps and data collection capabilities. The project enabled learners to train their skills by recording scientific notes, images, and sound at specific locations. Architecture students used the same application to identify construction styles and design patterns in particular areas of urban space and to understand the changes in construction development.

2.5.3.2 Learning in locations

Sociology, anthropology, psychology, economics, and language science have traditionally used location-based or location-specific supportive pedagogies of learning. In these studies, where students learn ***in*** situated, inquiry-based, and cooperative settings, students, through their learning objectives, are immersed in spaces of rich sensory experience. Paramount to this richness is the cultural, social, and/or economic signs that exist in location-specific learning spaces (Sharples, 2019). Such phenomena are physically visible or invisible and include, for example, the history of city districts, characteristics of communities of people, historical features in museums, and social-economic principles in shopping areas. Since the beginning of research in the field of mobile learning, studies on geolearning ***in*** locations using mobile technologies have been conducted.

Oppermann and Specht (2000) used the context-sensitive nomadic exhibition guide in their art gallery-based research study. The audio guide with play and skip controls, presented identical content of art pieces but in different modalities and forms of interactivity. The project included the evaluation of the visitors' navigation in physical space and the information selection of the guide's presentation to reveal patterns of interest and engagement. The visitors exploited the richness of the information quantitatively, with above-average presentation time per exhibit, and qualitatively, with audio and text presentations and additional graphics of the exhibits.

In Göth and Schwabe's (2008) mExplorer study, students were set interactive and contextualized tasks as a way of introduction to the campus. The project enabled students to use problem-solving skills in authentic locations. For example, students were asked to find information in a specific book located in one of the campus libraries. To complete this task, students first had to recognize that there was a particular library for the book they sought. Then they had to learn how to use the library information system on-site to obtain the code with the information of the book's depository. Using this library code required students to understand the organization of the library and to locate the book in its specific holding-place. The results of the study revealed that the students were able to acquire significantly more knowledge about information and processes within the campus and spatial understanding of where the important places are located than students with a classical introduction in the lecture hall.

2.5.3.3 Further affordances of location-based mobile learning

The examples of learning *about* a location (Section 2.5.3.1) and *in* a location (Section 2.5.3.2) with mobile technology demonstrate that the concept of constructivism and social constructivism is well implemented in LBML. The learner-centered approach, however, reveals that some learners are more immersed than others (e.g., visitors to the art gallery in Oppermann and Specht's (2000) study), and some are more passive or cognitively overloaded in terms of technology (e.g., the students in So et al.'s (2009) study). Most of the studies described above involved a mobile system with interactive maps to locate and navigate and to assist in spatial understanding and problem-solving. This understanding comes from direct and authentic problem-based learning immersion in the designated learning setting and through attaining a sense of scale, perspective, and relationship to parts of the immediate environments (Sharples, 2019). The affordances of mobile devices are learner-centered activities to acquire, modify, and construct knowledge in different forms with the benefit or learning outcome of real-world experiences and situated memories. The natural environment fosters learners to discover the unknown or to put classroom learnings into practice with well-structured and ill-structured problem-solving activities, making the learning process the responsibility of one's self (E. Brown et al., 2010).

Location-based games such as Geocaching, Ingress or Pokémon Go

With the rapid growth of mobile technology, mobile devices have become very popular for mobile games, especially for the present generation of students, playing online games to a greater extent than previous generations (Huizenga et al., 2009). Location-based games (LBG) have been around since 2000. LBG transform real environments into a virtual world, where players have to move around in real life to explore the virtual world and perform tasks related to the game itself (Huang et al., 2018). According to the game objectives, players may collect virtual objects to achieve benefits in the virtual world, or even in the real world. The first popular LBG was Geocaching[8]. Its goal was to seek treasures and tackle individual missions and puzzles. Several studies reported enthusiastic, focused, and engaged participants (Christie, 2007; Clough, 2016; Ihamäki, 2007; Wetzel, 2019; Zecha, 2012). Further examples of popular LBG include Ingress and, more recently, in summer 2016, during explorative studies of this dissertation, Pokémon Go.

[8] https://www.geocaching.com/play (01.01 2020)

Mobile game-based learning makes it possible to add a fictional layer to the learning setting to enhance the motivation to learn and to immerse learners in the game for a couple of hours. Mobile games include examples such as role-based learning of history education (Huizenga et al., 2009), interactive learning of new economy (Marković, Petrovic, Kittl, & Edegger, 2007) or learning of sustainable development (Schaal & Lude, 2015).

Location-based mobile learning games

Edmonds and Smith (2016) studied the impact of location-based mobile learning games (LBMG) in higher education courses where students had to play and design a location-based mobile learning game. The study revealed active, engaged students with high intrinsic motivation. In educational research, Schmitz et al. (2012) distinguished different design patterns in their analysis of mobile learning games and their effects on affective and cognitive learning outcomes. Essentially, combinations of patterns that occur together in educational games, could be identified, the impact of individual patterns are hardly empirically investigated, and the results are fragmented and inconsistent.

To benefit from using mobile phones in education, teachers must be familiar with phones' affordances (E. Brown et al., 2010; Crompton, 2013; Sharples et al., 2005; J. Traxler, 2005; J. E. Traxler & Wishart, 2011). Schito, Sailer, and Kiefer (2015) presented a 6-step didactic planning framework for the integration of LBMG into formal education, considering the affordances of learning theories and by listing relevant factors that need to be taken into consideration.

2.5.4 Effectiveness of location-based mobile learning

Evaluation in the context of educational research focuses on understanding how fundamental learning processes can be taught, improved, and transformed (Sharples, 2009). The exploratory research of mobile learning focuses on usability, satisfaction, and qualitative results regarding effectiveness. A useful way of approaching evaluation quantitatively is to examine the effectiveness of summative assessments of the extent to which teaching benefits from the LBML method. To gain insights into significant cognitive learning outcomes of LBML, based on statistical measure effect size[9], the following examples are provided:

Cognitive learning outcomes of the mobile city game, Frequency 1550

Huizenga et al. (2009) implemented a GPS-based mobile city game called Frequency 1550. The game included maps of medieval Amsterdam to evaluate the effectiveness of LBML. The study investigated the game's intervention with 458 students (aged 12 to 16 years) in Amsterdam, over a three-week period. Ten classes played the mobile history game, while

[9] Background information of the statistical measure effect and a selection of educational factors that are relevant regarding LBML are explained in Appendix 1.

the other ten classes received a regular, project-based lesson series in the classroom. The results revealed that the game-playing students answered the questions significantly better (60%) than the classroom-based students (36%), with an effect size of d=0.62. The results also showed that students from higher levels of education profoundly benefited from playing Frequency 1550, than those at lower levels. Conversely, students with an initially low cognitive ability about History benefited more from playing Frequency 1550 than those with a higher level of initial ability. Frequency 1550, thus, appears to be particularly worthwhile for students with initially low cognitive ability, and students attending higher educational levels.

Cognitive learning outcomes with a mobile plant learning system

Huang et al. (2010) implemented a mobile plant learning system (MPLS) in the science curriculum in Taiwanese elementary education. The system was designed to evaluate the effectiveness of the new LBML system. The study involved 32 students (with an average age of 11) undertaking a botany course. It investigated the knowledge progress of plant learning, amongst students, by reproducing the name, ecology, function, type, and category of a wide variety of plants. The experimental group students used the MPLS as treatment, and the control group of students used the common guidebook. A pre-course and post-course test were conducted to determine the students' knowledge of plants and to collect the students' attitudes and perceptions by way of a questionnaire. The results showed that the average of the MPLS group scored significantly better (14.25) than the guidebook group (12.37). The responses to the questionnaire indicate that students appreciated the outdoor plant learning activities and the use of the mobile phone and its many functions. The study found that the use of mobile phones can stimulate students to engage enthusiastically in assigned learning activities, as well as encourage social interaction and discussion about the course material. At the same time, the guidebook group, using paper and pen, felt that making informal reports was easier than the PDA used by the MPLS group. Approximately half of the students encountered technical problems in handling the MPLS, whereas only one-third of the students claimed they enjoyed using the MPLS as a plant learning tool.

Cognitive learning outcomes with a mobile learning environment

Looi et al. (2011) implemented a mobile learning environment (MLE) and conducted a mobile inquiry learning experience for primary grade three students (8-9 years-old) over 21 weeks in Singapore. They compared a class of mixed-ability students using mobile phones and the MLE as a learning hub to integrate formal and informal learning activities with eight other mixed-ability classes without mobile phones. The LBML lessons in science were co-designed by teachers and researchers supporting inquiry learning in and outside of class, including planned home and informal activities, as well as class field trips to the zoo, a park, and a factory. They applied multiple guidelines to these lessons, including: student-centered designs; inquiry-based learning activities; access to a variety of multimedia content and recording tools available on the mobile phones; formative assessments questionnaires; the facilitation of collaborative interactions, community support, and resources; and support of teacher development by the researchers. The students' general science examination scores were collected before and after the mobilized science curriculum activities. The results showed that the intervention class using the mobile phones had a statistically significant higher exam score among all the mixed-ability classes. The researchers detected a shift in the behavior of the whole class after the introduction of mobile devices. The students were more engaged and able to undertake more constructive research by formulating questions, acquiring skills to perform an online search, collecting data, and producing quality content and concept maps to reflect their understanding and ability to negotiate meanings. Positive results were also achieved with the teachers. They demonstrated an increased agency and attitude in delivering the science curriculum in the mobilized class and spent more time with the students voluntarily compared to traditional curricula.

The three examples presented were all used in a school context, partly with gamification elements such as the GPS-based mobile city game of Huizenga et al. (2009). Schmitz et al. (2012) reviewed practical research papers on the effects of mobile learning games. The findings indicated that mobile learning games have the potential of both affective and cognitive learning outcomes. Concerning knowledge-based learning, empirical evidence is fragmented. In general, the empirical evidence in their literature review was inconsistent in terms of study design, instruments, procedure, and the statistical basis (dependent/independent variables), as they addressed different research interests. And in most studies, the novelty of the technology has probably played an essential role in the motivation and engagement for learning.

2.5.5 Relevance to this dissertation

The LBML methodology is utilized in several research projects and provides significant insights in various fields ranging from formal education to location-based mobile games. Mobile phones are used to allow (1) contingent learning, permitting learners to respond anywhere and anytime, (2) situated learning, in which learning takes place in authentic surroundings, (3) authentic learning, in which the task directly relates to the goals, (4) context-aware learning, in which learning is influenced through location and time, and (5) personalized learning, in which learning is customized for each unique learner in terms of abilities, interests, and preferences (Crompton, 2013; Sharples et al., 2005; J.

Traxler, 2005; J. E. Traxler & Wishart, 2011). The convergence of location-aware mobile technology and situated learning enables both personal learning environments, for informal lifelong learning, and location-based mobile learning, for formal learning in educational settings. Location-based mobile learning encompasses education that takes place in and about locations.

Despite positive results regarding LBML satisfaction and effectiveness (Huang et al. 2010; Huizenga et al. 2009; Looi et al. 2011), the novelty factor has played an essential role in the affective outcome. It is also likely that students show enthusiasm for and engagement with LBML lessons when taught in the regular school curriculum. This dissertation aims to answer this question, addressing research question **RQ3**, with the experimental study conducted in a real school context that is reported in Chapter 4. The study obtained results on how LBML performs with respect to real examinations and on the sustainability of the effects of an LBML activity on cognitive and affective outcomes over several months. The study further extracts the observed challenges of the LBML context that are likely to be relevant to the learning process. Furthermore, according to Hattie (2013, 2015), influences, such as from curricula, teachers, teaching, and learning approaches are related to learning outcomes. Therefore, the study results are discussed and reflected upon by addressing research question **RQ2** with the investigation about the learning designs and the associated teachers' ability to teach LBML and to cope adequately with the many contextual aspects.

2.6 Spatial reasoning and geospatial technologies

The ability to spatialize -the understanding of space - initially arises from humans' interactions with the geographical world of space-time (National Research Council, 2005). For centuries, designs of map-like spatializations have sought to inspire and stimulate the imagination, knowledge, and the exploration of unknown landscapes through the communicative power of their work (Kerski, Demirci, & Milson, 2013). The maps, today, are used to represent results from our interactions with the everyday world (e.g., pictures, graphs, maps) to spatialize the relationships between areas and regions, including, changes in perspective, scale, transformation, rotation, and pattern search. For this purpose, humans have to transform information into a spatial form that is perceptible to the eye (National Research Council, 2005).

The knowledge spatialization and the analysis of spatial relationships with geospatial technologies are an essential aspect in LBML insofar that they situate the learning objectives and foster geospatial awareness and spatial literacy. Furthermore, geospatial awareness is interdisciplinary and is more relevant than ever in terms of tackling contemporary issues such as climate change, economic globalization, urban sprawl, or global health impacts such as the outbreak of the Coronavirus (COVID-19) (Wang, Horby, Hayden, & Gao, 2020). Addressing these issues requires a society that can see the big picture, including the geographical component. Addressing these issues also requires an understanding of how different geographical patterns and trends are interrelated, from the global to the local scale (Hegarty, Burte, & Boone, 2018).

Goodchild (2006) calls for the implementation of spatial competence in core curricula, at the same level as in mathematics and linguistics. With spatial competence, Goodchild speaks of a transdisciplinary literacy across science, technology, engineering, and mathematics (STEM), social sciences, and art, which can be supported by using geotechnologies, namely Geographical Information Systems (GIS). Spatial thinking is not restricted to any domain of knowledge (National Research Council, 2005).

2.6.1 Spatial cognition and spatial thinking in education

Spatial cognition is a branch of cognitive psychology that investigates how people acquire, represent, use, and communicate knowledge about their environment to determine where they are, how they preserve resources, and how they find their way home (Mark et al., 1999).

Approaches to the development of spatial competence

Spatial cognition is essential for many scientific and technological breakthroughs, to everyday life, and at work of an increasingly mobile society (National Research Council, 2005). Different disciplines (such as cognitive psychology, neurosciences, astronomy, geography, geosciences, geoinformatics, and cartography, etc.) study spatial cognition in different species, especially in humans. Cognitive psychology and neuroscience work together to examine spatial cognition in human brains and to determine the surrounding neurobiological infrastructure. According to neuroscientists Newcombe and Huttenlocher (2000), three theoretical approaches form the basis of the development of human spatial competence:

- Advocates of **Piaget's theories** (Piaget, 1954; Piaget & Inhelder, 1948) argue that babies are born without spatial knowledge. Babies, they believe, develop knowledge from direct experience and interaction with their environment.
- **Nativists** such as Pinker (2003) contend that the essential aspects of spatial understanding are innate and that the biological maturation of specific brain areas can explain elements of spatial development that are not considered at birth.
- **Vygotsky's** (1980) **theoretical approach** emphasizes the cultural and social transfer of spatial skills.

Newcombe and Huttenlocher (2000) argue in favor of an interactionist approach to spatial development that integrates key findings from the above-stated classical approaches. They demonstrate how biological preparedness interacts with the spatial environment that infants encounter after birth to create spatial development and mature spatial competence. These are, for example, tracking a moving object, locating an object or event in its spatial arrangement, and understanding how the parts or features of an object combine to form an organized whole (Stiles, 2001). Gardner and Hatch (1989) described the existence of a visual-spatial intelligence in their theory of multiple intelligences, which is stored in both declarative (explicit) and perceptual (implicit) long-term memory (see Figure 2).

2.6.1.1 Spatial cognitive processes

The key to spatial thinking for problem-solving tasks is based on a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning (National Research Council, 2005). Space provides the conceptual framework within which data can be integrated, related, and structured as a whole. Representations provide the forms within which structured information can be stored, analyzed, comprehended, and communicated to others. Reasoning processes provide the means of manipulating, interpreting, and explaining the structured information.

2.6.1.1.1 The concept of space

The geographic information in a space-time approach

The concept of space distinguishes between field-based and object-based approaches to spatial information and is generalized to any location-based framework, in particular space, time, and space-time (Galton, 2004). For the inclusion of time in GIS, it can be distinguished between conventional "three- plus one-dimensional" approaches (space with time) and four-dimensional approaches (space-time). The geographic information in a space-time approach is reduced to a primitive form as an association between a point location in space-time and a property, termed as geo-atom (M. F. Goodchild et al., 2007). For example, a geo-atom might indicate that at 120°W, 34°N, at 0 meters above mean sea level, and at local noon on 11 July 2005, the Celsius temperature was 20°. Primitive spatial relations distinguish between static (distance, direction, topology, dimensionality (2D, 3D, 4D)) and dynamic (motion, flow, force, intersection) primitive spatial relations that makes spatial thinking a particular form of thinking (Burgess et al. 2002; Iaria et al. 2003).

By understanding the meaning of space, we can use its static and dynamic properties as a means for structuring problems, for finding answers, and for expressing solutions, which is relevant in the context of LBML and the handling of spatial and spatio-temporal data (National Research Council, 2005).

2.6.1.1.2 The tools of representation

Representations provide the forms within which structured information can be stored, analyzed, comprehended, and communicated to others. The tools of representation distinguish between internal and cognitive (mental images) and external and graphic (geometry, visualizations), linguistic, and physical, and so forth (National Research Council, 2005).

Internal, cognitive representation

The internal representation of spatial thinking is expressed as mental representations of geographical space to help people remember, understand, reason, and communicate the properties and relationships between objects represented in space (such as streets or city districts). The coding and application of spatial knowledge from the perceptive-motoric direct experience take place in spaces of different scales (D. Montello & Raubal, 2012). According to Montello (1993), these scales are divided into a figural, vista, or environmental categories. For these various scales, specific characteristics about spatial-cognitive questions, such as reference systems, must be considered (National Research Council, 2005). A widely accepted model of spatial learning proposes that spatial knowledge of places in the physical-geographical space develops in a sequence of three stages or elements (Siegel & White, 1975). People implicitly and purposefully encode knowledge about prominent objects (landmark knowledge), network structures that connect or relate places as lines (route knowledge), and the environment as a distorted surface (metric or survey knowledge). Ishikawa and Montello (2006) showed that these stages do not necessarily occur in a strict sequence from landmark to survey knowledge. With the encoding, some people successively acquire survey knowledge in the form of subjective, cognitive maps (concept or mental maps) surprisingly quickly, essentially as soon as they encounter a new place, at the same time, some people very slowly develop comprehensive survey knowledge of their surroundings. At all scales, people learn geometric characteristics such as connections, containments, sequences, distances, directions, forms, and configurations (survey knowledge) (Downs and Stea 1973; Montello and Raubal 2012; O'Keefe and Nadel 1978; Siegel and White 1975). This resulting cognitive map is a personal representation that can transform and systematically distort actual distances and directions between places. Drawing mental maps are an effective way of assessing spatial memory. (Gardony et al., 2016) presented software for quantitative analysis of sketch maps based on pairwise comparisons between landmarks, as well as bidimensional regression parameters.

External representation

The external representation of spatial thinking is expressed through iconic spatial symbolization with graphic and volumetric representations of spatial and non-spatial information (D. Montello & Raubal, 2012). On all scales, though mainly in small formats, we learn through symbols (e.g., the cities of Africa via a map). According to Bruner (1966), two-dimensional symbolic representations such as maps, drawings, and diagrams are assigned to the abstract-symbolic phase, and they need corresponding pre-structures to be applied in the learning context (see Figure 4). Photos, films, and other pictorial representations, as well as three-dimensional volumetric representations such as physical models and classical globes of geography, belong to the iconic phase (D. Montello & Raubal, 2012). By visualizing relationships, we can perceive, remember, and analyze the static and, via transformations, the dynamic properties of objects and the relationships between objects, which is important in the context of LBML, addressing spatial and spatio-temporal data (National Research Council, 2005).

Linguistic representation

The linguistic representation of spatial thinking is manifested through the use of spatial semantics to communicate the spatial properties of individual entities and relationships between objects (D. Montello & Raubal, 2012). There are considerable differences between the sense of graphics and volumetric representations and that of natural language representations. However, the spatial description may contain surprisingly similar spatial information content, such as the description of routes in sketch maps (Tversky & Lee, 1999). Pruden et al. (2011)

investigated in a longitudinal study design that children who produce more spatial language are more likely to perform better on spatial problem-solving tasks at a later age, which is relevant for wayfinding tasks in collaborative LBML designs.

Physical representation

The cognitive importance of landmarks is reflected in neurophysiology. Landmarks are recognizable features used for navigation. Empirical findings from neurobiologists (N. Burgess et al., 2002) show that spatial cognition can be located in the brain's hippocampus (O'Keefe and Nadel 1978). The hippocampus represents, in general, episodic memory. The grey matter volume of the hippocampus is much more developed, as shown by rats' explicit reference to their hiding places (O'Keefe and Nadel 1978). This neuroscientific finding was proven in humans also, as shown in a study on London's cab (Maguire et al. 2006). To obtain their driving license, taxi drivers in training drive around the city of London on mopeds for three to four years, memorizing a labyrinth of 25,000 streets. "The Knowledge", as the test is known, contains a series of grueling questions with a pass rate of 50 percent. Maguire et al. (2006) discovered that London taxi drivers had more grey matter in their anterior hippocampi than people who were similar in age, education, and intelligence but did not drive taxis. The cause of why the brain should expand to meet the cognitive demands of London's streets is unknown, as is the question as to whether The Knowledge test selected only people whose spatial intelligence was above average. To answer this question, Woollett et al. (2009) investigated in a longitudinal comparative study a group of prospective taxi drivers who studied for The Knowledge test against a group of non-taxi drivers to measure the growth of their hippocampi with magnetic resonance imaging (MRI). After four years, the successful graduates who passed The Knowledge test showed that the hippocampi had grown over time (Woollett et al., 2009). Schinazi et al. (2013) confirmed Woollett et al.'s (2009) findings in an empirical study, concluding that people who can produce cognitive maps of new areas tend to have larger hippocampus size. By using both the external representation with maps and symbols and the use physical features for navigation, LBML can make an important contribution to the promotion of spatial thinking.

2.6.1.1.3 The processes of spatial reasoning

Spatial reasoning processes provide the means of manipulating, interpreting, and explaining the structured information. The processes serve the purposes of descriptive, analytical, and inferential functions, which are interrelated in their use (National Research Council, 2005).

The **descriptive** function extracts the appearances of and relations among objects (boundary, center, path, network, sequence). It includes distinguishing and encoding spatial features of the world as figures from ground, evaluating size, etc. (National Research Council, 2005).

The **analytical** function enables an understanding of the structure of objects (perspective, 3D to 2D transformation, scale, interpolation, generalization). The analytical spatial reasoning includes how people represent spatial information and navigate the world, especially in relation to wayfinding. Wayfinding is a fundamental process of geographical space that occurs with great purpose (Sorrows & Hirtle, 1999). The specific tasks of wayfinding include creating and selecting a route, creating and maintaining orientation for one's starting point or external features or locations, and recognizing how landmarks behave spatially with each other (D. Montello & Raubal, 2012). Other environmental aspects of wayfinding are assessing distances, recalling sequences of directional turns, and remembering the location of objects or events. Wayfinding is further used to plan spatially distributed locations such as sequencing multiple destinations or scheduling travel needs and route design. Wayfinding involves awareness of various modalities of movement, such as walking and driving, and the classification of psychological spaces (figural, vista, environmental, geographical) (D. R. Montello, 1993). Spatial disorientation involves various aspects such as not knowing where the user is, where and how to go to the next place, and how to locate something that is considered an exit point in a space (Sorrows & Hirtle, 1999). Navigating in unknown environments (exploring) or to unfamiliar places (quest) can be technologically assisted by navigation systems. Navigation systems are popular for reasons of efficiency (faster reaching the destination) and lower cognitive load (Allen, 1999). Due to their extensive use, however, navigation systems are recognized for having several adverse effects on spatial knowledge acquisition (Gardony et al., 2013; D. R. Montello, 2005). If, for example, pedestrians direct their full attention – with head down - to the display of the smartphone and, in doing so, observe less of their surroundings, they may encode less spatial knowledge in short-term memory (Ishikawa & Montello, 2006) and risk serious accidents (Lin, Kuehl, Schöning, & Hecht, 2017).

Locating the origin of cities in Piaget's Geographical Study

The **inferential** function generates answers to question about the functions of static and dynamic objects (spatial correlation; spatial dependence; causation). It includes how people mentally restructure (decode) a cognitive map to make decisions together with internal representation (prior knowledge) (D. Montello & Raubal, 2012). Spatial correlation and causations an integral part of daily decision-making activities and in Geography education. An experiment by Bruner (1959) successfully demonstrated the value of spatial, problem-oriented thinking, and how best to prevent inert knowledge acquisition. In

Geography, fifth-grade students learned one of two ways to locate the urban development of the northern central states of the United States. The first group was given the inductive approach that "cities spring up where there is water, where there are natural resources, where there are things to be processed and shipped. The other group passively experienced that there were arbitrary cities at arbitrary places by arbitrary bodies of water and arbitrary sources of supply" (Bruner 1959, p. 188). Both groups had to draw the most important cities, railways, and motorways on blank maps, containing only tracings of the rivers and lakes of the area as well as the natural resources. In the discussion, the students had to justify their results. The outcome was that only the first group could explain their findings with the inductive approach. The other group tried to retrieve some names and positions as more randomly registered contents.

2.6.1.2 Spatial competences in education

The National Research Council (2005) explains in its '*Learning to Think Spatially' report*, that the intentional teaching of spatial thinking in education is valuable, that spatial thinking must begin with students and that it is taught often and in a profound way. The council summarizes four directions of competences to acquire spatial competences in K-12:

- Students naturally use **spatial thinking in an informal** environment - they know where, when, how, and why they should think spatially.
- Students consciously use **spatial concepts in school**. They do so through a deep understanding of spatial concepts and spatial representations, through familiarity with a variety of spatial analysis techniques and based on assistive technologies such as maps or Geographic Information Systems.
- Students adopt a critical **attitude towards spatial thinking.** They evaluate the quality of spatial data and models based on their source and validation techniques.
- Students present arguments or points of view when solving problems and **validate the results through spatial information**.

Skills in spatial thinking are acquired within a specific context and are supported by tools and technologies. Seitinger (2009) proposes two learning objectives related to multimedia tools:

- Learners develop a spatial **understanding**, such as the ability to understand space through perception and cognition through a variety of modes of representation (enactive, iconic, and symbolic).

- Learners develop skills about how to **interact** in geographical spaces with multimedia techniques, such as the ability to move physically or virtually through space and influence an environment.

Spatial thinking at primary and secondary schools

Wakabayashi and Ishikawa (2011) analyzed the curricula of English-speaking countries according to the existence of spatial literacy. In K-12 curricula, spatial literacy was listed in geography, mathematics, and natural sciences only occasionally. Mathematics developed the basics of spatial concepts (figural scale), and geography and environmental sciences applied these concepts (environmental scale) to practice without specifying concrete conditions and techniques. Regarding teaching material, textbooks show that at a lower level, spatial concepts and fact-oriented teaching strategies are available that require little spatial representation. Educational objectives that require spatial skills and higher-order problem-solving - in the context of technologies such as GIS - are rarely discussed (Wakabayashi & Ishikawa, 2011).

2.6.2 Mobile GIS for spatial reasoning

Every day, millions of decisions are made based on activities and systems wherein geographic location is a fundamental feature. Geographic problems are those that involve aspects of location (Longley et al., 2011). Solving geographical problems requires spatial thinking. Such thinking, however, is often complicated and beyond the abilities of a single person's skills or viewpoint. For this reason, many complex decisions about spatial reasoning involve the use of Geographic Information Systems (GIS). A GIS is a computer system for the acquisition, storage, processing, analysis, management, and visualization of spatial or geographical data (Longley et al., 2011). GIS capabilities allow for new locations to forecast the weather, and identification and manipulation in terms of reporting traffic jams. GIS datasets from smartphone users can be analyzed and interpreted with map visualizations to understand mobility patterns, relationships, and trends, and have the ability to store these massive datasets.

2.6.2.1 Geospatial technology in education

Geospatial technology in education has a long tradition (Kerski, 2008). During the 1980s, the training predominantly focused on how to operate software to model the earth. In the 1990s, the spatial representation of data became a vital part of teaching spatial competence. After 2000, in addition to learning software, methods, and theory, spatial problem solving was considered important for decision-makers to understand spatial relationships and concepts to make better use of the technology. Consequently, GIS increasingly featured in secondary education curriculum (Kerski et al., 2013). Geotechnical technology became more practical, and educators began to use the technology in their disciplines, be it Biology, Geography, Earth Science, Chemistry, History, Mathematics, and Language Arts (Kerski, 2008).

One of the main functions of GIS is spatial analysis, the inferential function of spatial reasoning with technology. Spatial analysis can be used to uncover patterns that were not previously recognized. Patterns in the manifestation of, for instance, a disease can indicate the mechanisms that cause the disease. Some of the most famous examples for the introduction of a GIS and spatial analysis in secondary schools show the cholera case of 1854 (Longley et al., 2011).

Cholera case

In 1854, British surgeon John Snow (1855) investigated the cholera outbreak in the streets of London. Prior to Snow's investigation, the reason for the outbreak of cholera and the many deaths it caused (particularly in London's Soho District), was unknown. Snow sought to use a map to ascertain the cause of the cholera outbreak. Through sketches he made on a map, Snow proved that the deaths occurred predominantly in the Bond Street area, where a water pump was located. After Snow shut the pump down, the epidemic ended (Longley et al. 2011).

The causal research of Snow's spatial phenomenon can be reconstructed 150 years later in web-based geographical information systems. Figure 7 depicts the environmental features (deaths and water pump) shown on an interactive map as point symbol representation Colors are used to indicate the classification of recorded deaths from Cholera (colored according to closest pump).

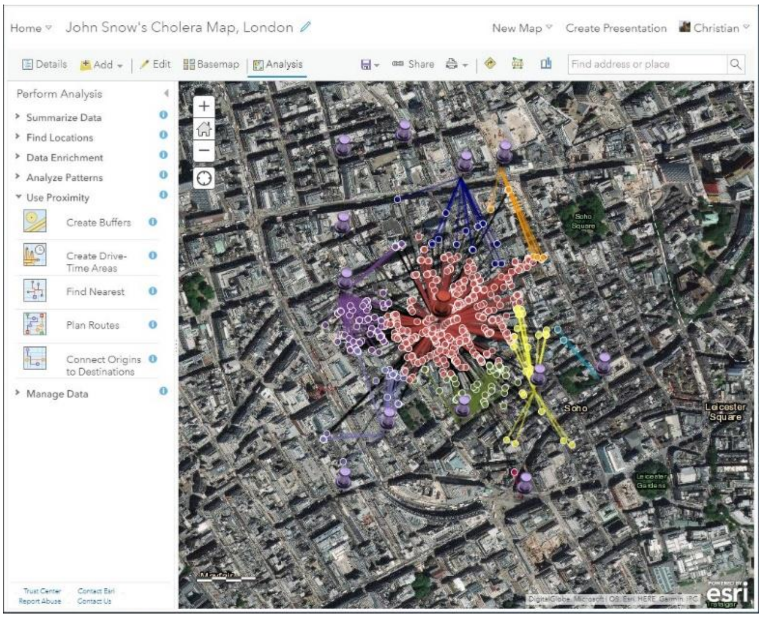


Figure 7 Analyzing John Snow's map of cholera outbreaks in London 1854 with ArcGIS Online by Esri Inc. https://arcg.is/1Dji1q (28.11.2019)

Mobile Mapping with GIS

The strength of a GIS lies in the fact that spatial problems can be analyzed quantitatively using geoprocessing tools. The distances of the closest pumping stations represented as line symbols are a result of the spatial analysis "Find Nearest Point". Such results uncover hidden patterns and typically generate further questions since they can be discussed in the context of maps and geographical data.

The approach of the GIS project with the Cholera example can be extended to field work by including mobile phone technologies and GPS. Field work is essential for understanding and appreciating our world (Kerski, 2011) The integration of mobile phones makes it possible to imitate the case of cholera in one's own urban space or near a school. Through the extension of mobile technologies, the GIS project becomes a physical component, such as in field-based education (see Section 2.4.2.2).

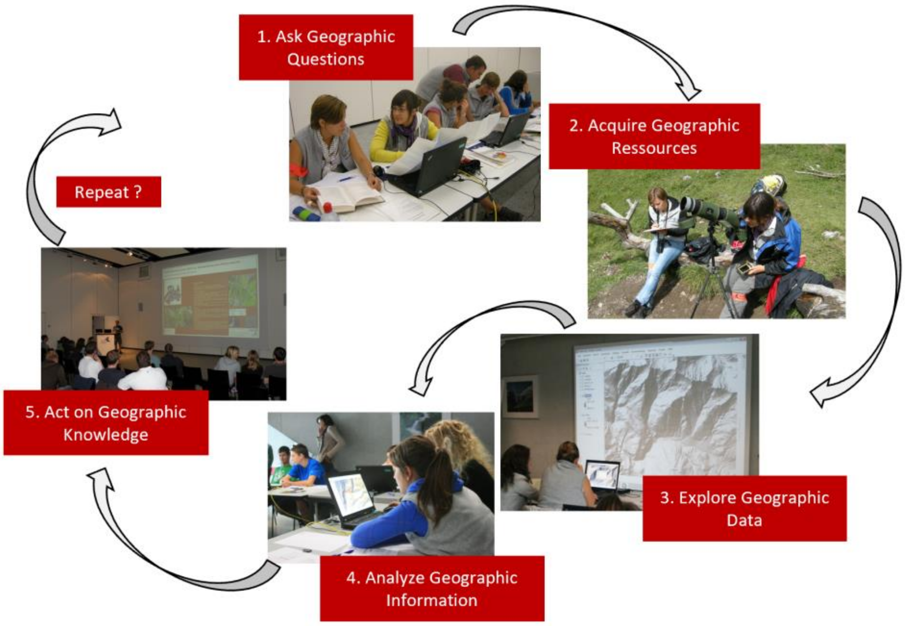


Figure 8 The geographic inquiry process based on Kerski (2011); Images © Esri Sommercamp 2009, 2010, 2011)

Relating the PADUA scheme of Aebli (1983) or the ADDIE scheme of Gagné (1985) (see Section 2.4.2.1), mobile GIS could be implemented in the cholera case with the geographic inquiry process in the school's outdoor surroundings (see Figure 8) (Kerski, 2011):

The geographic inquiry process

- Students create their specific research question and design a data model for the missing field data with a GIS platform.
- Students explore the virtual 'crime' scene and gather observations of the phenomena with GPS and attribute information using a mobile GIS application on their mobile phones (Beddall-Hill 2011; Lambrinos and Asiklari 2014). With the mapping, students collect their experiences actively and are triggered to exchange ideas, strategies, or questions on-site.

- Back at the computer lab, the collected datasets are qualitatively explored and reviewed in combination of basemaps as context information.
- The analysis of the geographic information includes the quantitative processing and evaluation to gain an added value of the investigation.
- The presentation of the results combined with whole-class discussions encourages students to teach and learn from each other in the Vygotskian approach to foster critical thinking skills.

Findings usually spark additional questions, which in case of self-regulated inquiries or student projects allow the opportunity for future processing in the project. The resulting cycle is the essence of geographic inquiry (Kerski, 2011).

2.6.2.2 Teaching strategies with mobile GIS

The example of the cholera case demonstrates that the use of GIS supports critical thinking and analytical skills (Kerski, 2003a). The National Research Council's (2005) report, *Learning to Think Spatially*, suggested embedding GIS technology in teaching strategies to promote the following skills:

- **Spatial concepts** are required when a learner creates a research question in ill-structured problem-solving missions or when He/she navigates using maps and spatial language to explain and find the way. Such concepts are also necessary when using spatially iconic symbolic representations when artifacts have to be mapped (Milson & Kerski, 2015).
- **Spatial mental representations** competence ensues when a learner encodes knowledge about matters such as prominent objects (landmarks), paths that combine start and target location (route knowledge), and the area covered by the tasks as a distorted surface (metric or survey knowledge) in the field with mobile GIS and GPS (Kerski, 2003b).
- **Spatial reasoning and spatial view** occur when a learner analyses the acquired data of several geographical phenomena and can discuss spatial dependences (similarities and differences). They further happen when a learner can conduct plausibility checks on matters such as: *Why are things located where they are? How are they affected by their proximity to nearby phenomena and by invisible interconnections and networks?* (Kerski, 2008).

The promotion of spatial competences of children and adolescents in formal education has been widely discussed across disciplines. With the orientation gaming app of Bartoschek, Schwering, Li, & Münzer (2013), children developed essential spatial competencies such as orientation, wayfinding, and map understanding. Flynn (2018) investigated spatial mental representation through experiential geocaching activities. His study included an investigation of required processes for orientation, directional abilities, and spatial overlay. It revealed processes such as dissolving and recognizing points, networks, regions/spatial shapes, and spatial patterns. Collins' (2018) paper verses digital map technology comparative study on spatial thinking skill acquisition revealed that both paper and digital media aid in developing and improving spatial thinking skill acquisition among eight grade students. In the case of digital data collection, however, the analysis of the collected data follows directly in the computer laboratory (see Figure 8). It also provides immediate feedback on the field work results and answers on related spatial reasoning, both of which are important for motivation and straightforward project procedure.

Bartoschek et al. (2013), Milson and Kerski (2015) illustrated that GIS and GPS use offers many positive experiences and opportunities in secondary and higher education. However, many teaching-related challenges remain (Kerski et al., 2013; Milson & Kerski, 2015; Christian Sailer, Schito, Kiefer, & Raubal, 2015). These challenges include a lack of contemporary teacher education, the absence of ready-to-use GIS material, the shortage of time for training and overall interest, and the scarcity of a core curriculum workflow published in academic literature (Kerski et al. 2013).

2.6.3 Summary and relevance to this dissertation

Learners in an LBML activity immerse in the physical environment and encode spatial entities in implicit and explicit ways. The explicit cognitive encoding elaborates the acquired knowledge, including map reading, orientation, and wayfinding skills, in semantic and episodic memory. Analysis of these spatial skills together can be used to find errors in orientation and wayfinding, determined by visually analyzing GPS tracks (Bartoschek et al., 2013). These findings can be significant when teachers choose to inspect learning activities remotely or when they conclude the remote activities together with the learners back in the classroom. Therefore, learner movement data and its recording are relevant to research question **RQ1** as it pertains to equipping an LBML system with GIS capabilities. In Chapter 3, the development and evaluation of the LBML system include a component to analyze learner trajectories. In Chapter 4, the trajectories are systematically analyzed to gain insights into the learning process and satisfaction, which are addressed by research question **RQ3.**

The creation of LBML activities requires spatial thinking skills and skills to use of geospatial technologies. This relates to the research question **RQ2** and is introduced in case study 3 in Chapter 3 (Section 3.3.1.3). Teachers require an awareness of the learner's limited capacity of human short-term memory (Sweller, 1994), limited processing capacity (Miller, 1956), and multimedia learning principles (Mayer, 2005) when designing an LBML activity in order to manage the various cognitive activities in time and place. Further discussions in Chapters 3,4, and 5 include performance considerations for the learning process when learners need to seek locations and to reason about the content and spatial aspects of problems in parallel.

Spatial reasoning in LBML activities takes place when a learner encounters a spatial problem-solving task *in situ* and solves the problem with or without maps. Such learning tasks encompass a series of cognitive processes that encourage exploration and discovery, investigated throughout the empirical studies of Chapters 3 and 4 to address research question **RQ3.** Spatial concept mapping is part of Chapter 4 when the ability to recall the situational context in the longitudinal study is investigated. It reveals indirect answers about the performance of spatial cognitive processes, which pertains to research question **RQ3.**

2.7 Conclusion

Western pedagogy of the 1930s did not consider learner autonomy and self-direction (Crompton, 2013). The paradigm was to reproduce facts and procedures without asking questions or making creative contributions. This view has changed over the last 50 years. Effective learning has been viewed differently, and learners have been encouraged to participate in their own learning processes actively. This pedagogical shift was fostered in part through the emergence of user-centered information and communication technologies. Today, mobile phones have redefined communication and interaction among humans and have radically transformed processes for acquiring information and knowledge. In Switzerland, for example, 99% of adolescents own devices with mobile data subscriptions (Suter et al., 2018). With the mobile phone as an extension of the self, young people today engage in many leisure activities with the coexistence of mobile audiovisual activities. The results of Suter et al. (2017) have shown that mobile phones foster multitasking, and activities such as browsing on the web, mobile gaming, and communication have become inseparable in the world of adolescents. Such activities are also part of popular LBML game applications (Edmonds & Smith, 2016). Outdoor play with LBML games typically makes learning pleasant, stress-free, and participatory through storytelling, rich digital media, location awareness, maps, augmented reality, and gamification strategies (Edmonds & Smith, 2017).

To benefit from using mobile phones in schools, teachers must be familiar with phones' affordances (Crompton, 2013; Sharples et al., 2005; J. Traxler, 2005; J. E. Traxler & Wishart, 2011). Teaching strategies regarding outdoor learning are widely discussed in the frameworks and guidelines of Hemmer and Uphues (2009) and Stolz and Feiler (2018) with respect to teacher and learner agency. However, Kranz et al. (2013) observed that the introduction of digital teaching designs in LBML often appears as a substitute for poor classroom instruction due to the lack of technology affordances and the relating didactic knowledge, although insights of empirical evidence exist. Woodli (2007) suggested a 4-step didactic planning framework for LBML in GIS education, including requirements analysis, specification, implementation, and execution/evaluation. Neeb (2010) investigated different instructional approaches for outdoor learning on motivation and referred to the impact of careful methodological–didactical planning of excursions. Schito et al. (2015) presented a six-step didactic planning framework for the integration of location-based games. Furthermore, digital teaching requires the awareness of the cognitive aspect of multimedia learning with mobile phones, described in several principles by Mayer (2005). In addition, the amount of information, described as the cognitive load

(Sweller, 1994) is a critical variable in outdoor learning (Orion & Hofstein, 1994). Also, learners' visual and auditory channels have limited processing capacity (Miller, 1956) to elaborate on the perceived information and should optimally be supported in a complementary way. Furthermore, LBML means using skills such as map reading, orientation, wayfinding, cognitive mapping, and spatial reasoning that use other processing capacities to encode the spatial inputs in semantic and episodic memory (National Research Council, 2005).

The number of processes involved in LBML demonstrates that the required teaching abilities and the experience to select appropriate technology and pedagogy, together with time and organizational management, motivation, and endurance, requires a plethora of skills on the part of both learners and teachers. Therefore, the contribution of this dissertation is to provide insights into how teachers approach location-based mobile learning in real-world contexts based on empirical evidence and how students perceive and perform it.

3 OMLETH: A location-based mobile learning system

Spatial thinking is a prominent theoretical and empirical field of inquiry in geographic education research. As such, the inclusion of spatial thinking at all levels of education is essential for the sustainability of the planet in the 21st century (Arlinghaus et al., 2019; Flynn, 2018; Viehrig et al., 2019). The daily use of geographical tools, such as Global Positioning System (GPS), Location-based Service (LBS), and Geographical Information System (GIS), on mobile phones - to order a taxi, book a holiday, or find the fastest route - shows the relevance and importance of spatial problem-solving. The extent to which such applications contribute to improving spatial thinking is controversial, as Maguire et al.'s (2006) study on London taxis demonstrates, discussed in Section 2.6.1.1.2. However, location-based mobile learning (LBML) systems can be designed in such a way that situated learning on-site is sustainably supported by spatial thinking activities. Such activities include data collection, map analysis, and foster concept mapping, all of which can be used in project learning settings, including in-depth classroom debriefings.

This chapter outlines the research-based design (RBD) approach to the development of the LBML prototype in this study. RBD was used in three iterations and tested within real situations in formal education. The first solution of the prototype is described in Sailer, Kiefer, and Raubal (2015).

The remainder of this chapter is structured as follows: Section 3.1 introduces the research questions; Section 3.2 presents a short description of the release of OMLETH; Section 3.3 describes the design solutions and evaluations through empirical studies involving four case studies of OMLETH; and, Section 3.4 presents the conclusion from the lessons learned in this chapter.

3.1 Motivation and research questions

Geolearning (Sharples, 2019) is an LBML pedagogy that focuses on multimodal learning in a situated and authentic environment. It engages all the senses to create an integrated impression of a situation. It involves spatial thinking in combination with cognitive and metacognitive strategies, such as concept mapping, schematizing, analogy formation, cross-linking, and the assessment of situated learning content. Thus, the basic structure of an LBML architecture requires technology in which the contents are available in multimedia, linked with a georeferenced and are visualized at different map scales. Furthermore, to debrief and deepen the reflection process, the systems should be capable of capturing the learning process based on spatio-temporal footprints.

Between 2007 and 2014, Zydney and Warner (2016) examined 34 location-based systems for mobile learning, including 17 tools with GIS capabilities, including interactive base maps and basic data collection functionalities. However, none of the systems offered a straightforward way to refine LBML with contemporary GIS web features or the ability to configure and control the operation. As a result, a new approach was necessary.

Several requirements were factored when designing how LBML lessons in Swiss secondary schools and universities would be implemented and evaluated. The solution required an organizational structure that could map the semester structure of an educational institution. It was also important that the entire teaching process was covered, including the preparation of teaching materials and the implementation, analysis, and storage of learning activities. Furthermore, users needed direct access via web-browsers to overcome platform dependency, low technical barriers, and no subject-specific design limitations. It was acknowledged that the system should neither favor a learning model, such as for instance, behaviorist drill and practice, through closed-ended question type surveys nor a media, through distinct multimedia formats, such as audio. The system should force the creator to decide which pedagogical approach should be implemented through which content and tools. The system, therefore, required an easy connection to existing mobile-friendly content or tools, such as multimedia information and communication technologies (ICT), learning management systems or productivity tools, to motivate teachers who were already actively using digital technologies and content in the school context. Finally, it was noted that long-term maintainability and adaptability were important in terms of ensuring that the system could evolve and that existing teaching units could be reused and refined over several iterations. The first research question that was investigated, relies on MRQ1 (see Section 1.2), was as follows:

RQ3.1:

What are the key features of an LBML system with advanced GIS and multimedia capabilities that cover the entire teaching process of LBML?

The use of technology has become established in school and university teaching, often as a complement to traditional learning (Kranz et al., 2013). There is a risk, however, that e-learning tools or so-called "idiot-proof" solutions according to Hattie (2003) might replace didactic planning and preparation, leading to poor quality implementation. The influence of technology on the teaching design needs to be considered when implementing a new system. Consequently, the second goal of the research presented in this chapter relies on MRQ2 (see Section 1.2), including the systematic observation and evaluation of both teachers and students of secondary and higher education.

RQ3.2:

How do teachers conduct LBML teaching, including the planning and preparation, the execution of the LBML unit, and the debriefing?

To address each of the questions within RQ3.2, this chapter presents the components of Design-Based Research (DBR) (Dunleavy & Dede, 2014). The exploration consists of research findings from related work and case studies in real-world contexts to determine which design elements work well in practice, and which need to be revised and retested. The constructive part consists of the design and implementation of the system's solutions.

3.2 The system OMLETH

This section introduces the OMLETH system and provides an overview of its final release. Section 3.2.1 provides a schematic overview of the client-server system architecture. Section 3.2.2 presents the components of the backend, the server components, and Section 3.2.3 describes the web applications, the clients, that are in use for creators and players.

3.2.1 System design

Ortsbezogenes mobiles Lernen an der ETH

OMLETH[10] stands for „**Ortsbezogenes mobiles Lernen an der ETH**“. Initially intended for evaluating university students at ETH, the OMLETH system supports the creation and execution of LBML activities outdoors. The generic nature of the map-based platform allows its use at all levels of education in any subject if the learner possesses basic orientation abilities and map-reading skills. Figure 9 illustrates the OMLETH system with its different components. The clients section illustrates the components of the system that users interact with, including end-user applications such as OMLETH-Creator, OMLETH-Player, and OMLETH-Viewer. Clients connect teachers and learners and their educational workflows, such as the creation and use of the content through the system. The OMLETH-Player is a mobile client application for playing LBML activities on mobile phones and tablets. The OMLETH-Creator is a responsive client application for creating content, and the OMLETH-Viewer is for reviewing the activities on tablets or desktop computers.

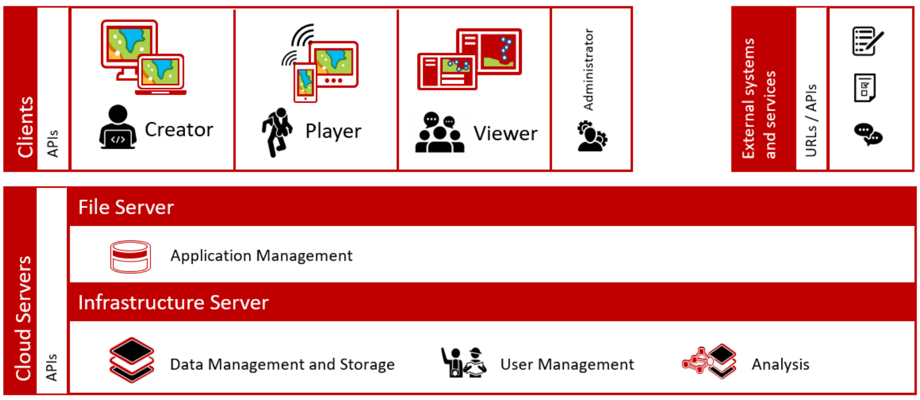


Figure 9 Schematic overview of OMLETH's system design

The cloud server component of the system includes file servers and infrastructure servers. The file server consists of the hardware and software to host the OMLETH clients. The infrastructure server consists of the hardware, software, services, and data repositories to organize users

[10] The OMLETH platform is accessible on https://omleth.ch (01.01.2020)

and connect them to the appropriate learning content on the GIS servers through Application Programming Interfaces (APIs).

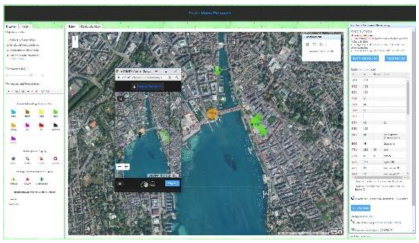
The infrastructure server also manages the permissions for users to perform distinct tasks or access to appropriate content based on predefined user roles. Both the file servers and the infrastructure servers have capabilities such as load balancing, high availability, and workload separation. The OMLETH system uses a combination of external systems and services to offer productivity tools, such as those for documentation, data collection and mapping, assessment, and communication. The ability to easily geo-enable other educational systems is a key capability of OMLETH.

3.2.2 Cloud servers

OMLETH's clients are hosted on managed cloud servers, including a software application that hosts the clients' Hypertext Markup Language (HTML5), Cascading Style Sheets (CSS), and JavaScript (JS) files. OMLETH's content and users are stored on managed cloud servers with GIS capabilities. The content includes the educational course structure, the learning content, the learner's data, and base maps, and is stored on GIS databases. The user management provides privileges to teachers and learners that can be used to control access to different clients. Each time users log into an OMLETH client, they are authenticated by the GIS server. The synchronization of the content works in two directions: maps and learning content are downloaded to the client, while local changes are uploaded to the server. Geoprocessing analysis, in combination with geolocation, is run on clients. For all traffic between the clients and the cloud servers, a secure connection (Hypertext Transfer Protocol Secure, HTTPS) is used.

3.2.3 Clients

Figure 10 shows a view of OMLETH's clients. The client applications are programmed as web applications in HTML5 and consist of three main parts: (a) the OMLETH-Creator, a web app for teachers and lecturers to create georeferenced learning content on interactive maps; (b) the OMLETH-Player, a mobile web app for learners to seek location-based learning content based on the devices' geolocation, and base maps to explore the surrounding environment; and (c) the OMLETH-Viewer, a web app with 2D and 3D components for teachers and learners to analyze and review the LBML activities and movement trajectories of learners in real-time.



(a) OMLETH-Creator

(b) OMLETH-Player

(c1) OMLETH-2D-viewer

(c2) OMLETH-3D-viewer

Figure 10 Overview of the OMLETH platform: (a) the OMLETH-Creator, (b) the OMLETH-Player, (c1) the OMLETH-2D-viewer and (c2) OMLETH-3D-viewer.

OMLETH-Creator

The OMLETH-Creator runs on desktop computers and tablets and provides editing tools that allow the learner to link learning content with geographical locations on an interactive map. The editing framework enables the creation of modules as tours of sequenced learning stations or free, self-regulated navigation activities with options to visit a station. Individual stations can encompass any pedagogy, such as instructions or well-structured and ill-structured problem-solving. Content can be provided in different modes, such as text, image, audio, video, maps, etc. Custom content, services, or systems, including websites, productivity web apps, or chats, can be retrieved directly through cloud services using their endpoints as URL. A created LBML module can be verified on an emulator (see Figure 10 (a) popup window on the map) that matches the edited content to the appearance and screen size of the mobile web application. Furthermore, a created activity can be shared for co-authoring or duplicated and applied – using the same base – to a different setting.

OMLETH-Player

The OMLETH-Player runs on any type of mobile device (smartphones and tablets of different operating systems and screen sizes). When an activity is started, the web app launches an interactive map showing the user's position in the center of the map. With active GPS reception and map reading, the learner is immersed in the exploration of the surroundings, orientates himself, and navigates to the learning stations according to the overarching tasks required to fulfill the mission. The learning content appears when the user is geographically inside the perimeter of a learning station and actively requests the content. A linked communication service, when enabled, ensures that it is possible to communicate with peers and the instructor within the exploration community.

OMLETH-Viewer

The OMLETH-Viewer runs on desktop computers and tablets and allows for teachers and learners to review and compare individual experiences with other learners through visual analytics in 2D or 3D maps. The maps display the learning content and the learner's movement trajectories and allow an analysis of distinct contexts, such as the content, the environment, or the collaboration. Location-independent access to individual stations allows for the debriefing of the activity from anywhere.

OMLETH-Administrator

The OMLETH-Administrator runs on desktop computers only and has the task of managing courses for teachers, lecturers, and other activity designers. An OMLETH-Creator user is explicitly assigned to each course and can create an unlimited number of LBML activities (modules), within that course.

3.3 Design solutions and testing

A fundamental assumption of learning science is that cognition is not a process that occurs within the individual thinker, but instead is a mental action that is influenced across context (teacher, tools, activities, etc.) (Barab & Squire, 2004). Learning and context are irreducibly co-constituted and should not be treated as isolated processes, which is why learning scientists have identified the need to develop tools, curricula, and especially theories that help them to understand and predict how people live, work, play, and learn with them (Leinonen et al., 2008). The investigation of learning in real contexts with systematic changes and evidence-based conclusions from these contexts is described as Designed-based Research (DBR) (Barab & Squire, 2004). The participants' socio-psychological, ethical, and aesthetic points of view collected through direct observations, surveys, or interviews play an essential part in the research result.

In this research, the aim was to include four case studies to test the prototypes to have a system that could conduct scientifically valid comparative LBML research in real educational contexts. The initial solution was based mainly on the results of a literature review, then primarily on the case studies. These studies focused on usability, effectiveness, and satisfaction. The first solution (see Section 3.3.1) was first tested with higher education architectural students and secondly with students and teachers of a secondary school science camp. The second solution, described in Section 3.3.2, was based on the requirements retrieved from the first two case studies. Section 3.3.2 also examines the new solution with a systematic evaluation involving university architects, including the same lecturers and curricula from the first solution but with new students. The third solution (see Section 3.3.3) included changes proposed from the second case study and was used to conduct preliminary research for the experimental study in Chapter 4. The iterations were organized into: (1) the design of features based on the requirements; (2) the development of the features; (3) the evaluation of the new prototype with one or two case studies and the focus on the new features; and (4) the results, which represented requirements for the next iteration.

3.3.1 First design and two case studies

This section presents the design and implementation of the first solution after a thorough analysis of state-of-the-art LBML systems. Section 3.3.1.1 presents the development considerations of the key features of OMLETH 1.0[11], which Sailer et al. (2015) introduced in their study on developing an LBML system with GIS features. The illustrations appear in "what's new in OMLETH 1.0"[12].

The testing involved a case study in a higher education setting, an architecture course in the Department of Architecture at ETH Zurich (Section 3.3.1.2), and a case study with secondary school students attending a science camp (Section 3.3.1.3). The second case study focused on gaining insight into learning analytics (LA) utilizing data from learners' trajectories.

3.3.1.1 System design of OMLETH 1.0

With this LBML system, the aim was to provide low technical barriers for lecturers and teachers as creators as well as students and pupils as players and a structure that fits with the organization of educational institutions, such as semester-related study programs. This subsection discusses the user interface of the creator in Section 3.3.1.1.1, the user interface of the player Section 3.3.1.1.2, and the operating environment in Section 3.3.1.1.3.

Integrated and web-based learning platform

Niegemann (2008) proposed the following five functions as a prerequisite for an integrated and web-based learning platform at educational institutions: (1) the creation of content and tasks; (2) the distribution of content and assignments; (3) the evaluation and assessment of the learning process; (4) communication tools; and, (5) administration. This diversification fits well with the designs of the LBML systems of Barak and Ziv (2013), Heimonen et al. (2013), Huizenga et al. (2009), Kohen-Vacs et al. (2012), and Santos et al. (2014). It was resolved to build different applications with user management that connect the users with the appropriate client applications and capabilities that are based on their

[11] https://omleth.ch/version/1 (01.01.2020)

[12] https://omleth.ch/version/1/Whatsnew_Omleth1.pdf (01.01.2020)

roles and privileges within the system. Lecturers require an interface (OMLETH-Creator) that enables the creation of learning content with a geographical reference. An interface for learners (OMLETH-Player) should allow access to the learning content based on geographic location. An application for the administrator enabled the administration of the courses (OMLETH-Administrator).

3.3.1.1.1 OMLETH-Creator

The user interface of the creator was intended to support lecturers and teachers in planning and preparing learning content on interactive maps. To achieve an efficient planning environment, Ako-nai and Tan (2013) and Kohen-Vacs et al. (2012) recommend a graphical user interface with an ample screen space for the map using large screens on desktop computers. Furthermore, large screens are still a convenient way to enter more extended portions of text, e.g., for commenting on methods or uploading content (Kranz et al., 2013). Ako-nai and Tan (2013) further suggest a drag-and-drop feature to sketch the learning stations on the map. Santos et al.'s (2014) system used a similar function, with teachers preparing the content directly during on-site inspections. Based on these findings, a responsive HTML5 solution with a sizeable area designated for the map was implemented. This approach allows creators to sketch learning stations anywhere, be it on large-screen desktop computers in the office or on tablets on-site.

The OMLETH-Creator was implemented using the Dojo framework (Dojo) and the ArcGIS API for JavaScript 3.x[13]. The application consisted of the following three main views:

Course view:

The course view included a catalog of creator-associated courses, which were managed by the administrator using a similar workflow to large educational institutions. When a new course was requested, the administrator created this and dedicated it to the creator asking it. Thereafter, the creator could create as many LBML activities as desired within the same course. These LBML activities were defined as modules.

Module view:

The module view included a catalog of modules which represented the mobile learning activities. Modules provided learners with general information that was accessible without location restrictions. The data model included a title, a description (story, learning objectives, etc.), organizational comments on the learning modules, and an access key – as suggested by Kohen-Vacs et al. (2012) and Heimonen et al. (2013) - to

[13] https://developers.arcgis.com/javascript/3/jshelp/inside_dojo.html (01.01.2020)

unify the individual modules. To ensure communication between groups, the system by Santos et al. (2014) was based on external services. Students and teachers shared experiences and results on Twitter, and students shared personal comments between each other on Whats App. Therefore, the module got an interface to integrate existing communication services by URL using, for example, the service Whats App[14].

Map view:

The map view included a map interface for the creation of the geographical content as learning stations. Here, the creator had the choice of a collection of base maps, including imagery, imagery with labels, streets, topographic, terrain, and OpenStreetMap (OSM). Each of these base maps provides rich geographical context as a reference. The place-based learning content was stored in a learning station that was represented as a polygon and the data model included different items, including: (1) the station number; (2) the title; (3) the description (story, case study, learning objectives); (4) the task description; (5) the URL integrated with external services by hyperlinks; (6) the follow-up station number; and (7) the follow-up task description. The integration with, or connection to, external systems or services was proposed by Kohen-Vacs et al.'s (2012) LBML system. A small tutorial next to the URL item was added, which discussed the productivity, data collection, and assessment tools and explained how to gather and embed the URLs of other learning management systems (LMS). Because Barak and Ziv (2013) made positive user experiences through the visual differentiation of geographical content in the activity categories knowledge or experience, the learning stations were differentiated into clearly distinguishable colors in terms of teaching, questioning, map analysis, spatial thinking and evaluation. To allow collecting discoveries as any kind of multimedia, a further entity was developed as point feature, called multimedia collector, that could upload any type of multimedia content created on mobile phones. The user of the web app was able to georeference single multimedia collectors as point features at distinct locations inside or outside a learning station.

3.3.1.1.2 OMLETH-Player

Mobile application development must be able to adequately contend with various challenges, such as screen dimensions, platforms, standards, protocols, and network technologies (Delia, Galdamez, Thomas, Corbalan, & Pesado, 2015). To support LBML, the software had to work

[14] On 21 January 2015, WhatsApp users were able to use the messenger app (even in a web browser), and group administrators were able to share these chats using a distinct URL. This sharing capability became popular with most communication services. Read more about on https://blog.whatsapp.com/614/WhatsApp-Web (01.01.2020)

optimally across a wide range of devices, such as tablets and large and small smartphones. Limited battery life, memory requirements, and the procedure to configure the location settings were taken into account to maximize usability and satisfaction.

In 2014, native applications delivered the best mobile experience due to their access to most device utilities (camera, video, GPS, accelerometer, etc.). These utilities had high-performance offline capabilities and background processing to issue context-based notifications when user attention was required (Delia et al., 2015). The disadvantage of native applications was that the source code could not be reused for different platforms. This resulted in greater effort and costs for application development (Delia et al., 2015). Therefore, to develop a mobile application only once and to run it on different platforms, front-end developers increasingly used cross-platform mobile development approaches (El-Kassas, Abdullah, Yousef, & Wahba, 2017). Delia et al. (2015) and Xanthopoulos and Xinogalos (2013) created a virtual teaching and learning environment and analyzed the following four development strategies, which allowed code reuse:

Cross-platform mobile development strategies

(1) **Generated strategy by cross-compilation**

Cross-compiled applications must be compiled natively for each target platform and achieve the same high overall performance as native apps (Delia et al., 2015). The most notable disadvantages of these applications are the additional time needed to complete the entire compilation step before testing, and the platform dependence of the generated binary code (Delia et al., 2015).

(2) **Interpreted strategy**

The code of interpreted applications is interpreted at runtime. Applications run through the code line by line and execute each command, allowing dynamic typing. The most notable disadvantage is the execution speed compared with that of compiled languages (Delia et al., 2015).

(3) **Hybrid strategy**

Hybrid applications use web technologies (HTML5, JavaScript, and CSS) inside native containers (WebView in iOS and WebView in Android) and leverage the device's browser engine to render the HTML and process the JavaScript locally (Xanthopoulos & Xinogalos, 2013). The main disadvantages of native applications are the negative effect on user experience because native components on the interface can not be seen, and the slower performance due to the load of the web container (Delia et al., 2015).

Mobile web application

(4) **Mobile web applications strategy**

These applications are platform-independent and launchable without installations or subsequent upgrades (Delia et al., 2015; Xanthopoulos & Xinogalos, 2013). Software libraries promise to simulate the functionality of native applications, such as jQuery Mobile using HTML5, CSS3, and JavaScript (Xanthopoulos & Xinogalos, 2013). Hardware access can be facilitated through several JavaScript APIs such as Geolocation, Drag and Drop, and Web Storage. Multimedia formats are supported through many HTML5 elements, such as video, audio, and web services like iFrames that embed an HTML document inside another HTML document[15] (Xanthopoulos & Xinogalos, 2013). The disadvantages of mobile web apps are the reliability of the network coverage in accessing the content, and the slower response times (Delia et al., 2015).

These four widely different development strategies show that, in 2014, no one or leading strategy regarding cross-platform development existed (Xanthopoulos & Xinogalos, 2013). Nevertheless, several scholars advocated the mobile web application strategy (see Barak and Ziv (2013), Heimonen et al. (2013), Huizenga et al. (2009), Kohen-Vacs et al. (2012), and Santos et al. (2014)), and, given that this aligned with the cost and time constraints and the skills in software engineering, OMLETH was implemented with the mobile web application strategy.

The latest jQuery Mobile web framework, 1.4.5[16] was chosen, which automatically adapted to different screen sizes and ratios for optimal use of the available space for the map. The framework is optimized for multi-touch interaction and implements interaction paradigms typical for mobile phones, such as navigation with hand gestures for intuitive control of the interactive maps, to ensure a fast learning curve when interacting with the application (Kranz et al., 2013).

Inspired by Kohen-Vacs et al. (2012) and Heimonen et al. (2013), a search box was implemented using the access keys in the header of the main view, which popped up when the Player started. The launched module provided the user with the first location-independent information and a view of the learning stations distributed on the base map.

Figure 11 (left) depicts a module in action. The map layout consists of a *Zoom* control with "+" and "-" buttons and an *Options* button, displayed with a sandwich icon. This icon affords access to the module's description and the external communication service and allows the user to switch between four different base maps (imagery, streets, topographic, and OSM).

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[15] https://www.w3.org/standards/webdesign/ (29.12.2019)

[16] https://demos.jquerymobile.com/1.4.5/ (01.01.2020)

To access the learning content, Santos et al. (2014) and Huizenga et al. (2009) used the technology-driven request approach of geofencing. Their LBML systems utilized spatial filters and triggered access to the learning content when the mobile phone's position crossed the virtual boundary of the learning station, the so-called geofence. Kohen-Vacs et al. (2012) used the learner-centered request approach of geofencing, where the user manually requested the learning station by pressing a button.

To meet the core objectives to foster user's spatial thinking, the approach of Kohen-Vacs et al. (2012) was chosen. Figure 11 (left) shows the "learning station request" button that appeared as a search button on the left side in the footer bar. The requests were handled by the HTML5 Geolocation API, which searched for learning stations within 10 meters of the geolocation position. Each request was confirmed with the placement of a blue circular graphic with a diameter of 20 meters on the map. When the device detected an intersection, a Green Book symbol appeared in the upper right corner of the map and indicated a successful hit. When the Green Book menu was pressed, the learning content was displayed in a new page window shown in Figure 11 (right). It included all necessary information about the learning stations as well as the button controls for jumping to linked web applications if available. The blue circle of the learning station request could also serve as orientation.

Figure 11 OMLETH-Player 1.0 (left) with the map GUI, learning stations (pink polygons), and the blue circular graphic; (right) Popup containing the content of the learning station

Position tracking

Niegemann (2008) stated that the evaluation and assessment of the learning process is one of the key features of a learning management system. This feature has emerged with two main directions, educational data mining (EDM) and learning analytics (LA):

- **EDM** is concerned with statistical methods for discovering patterns of data garnered from educational settings to understand better learners and the context they learn in.
- **LA** encompasses the measurement, collection, analysis, and reporting of these datasets to optimize learning and the environments in which it occurs (Siemens & Baker, 2012). Because learning is a process that happens over time, a core characteristic of LA is the generation of high-resolution temporal data (Knight & Friend Wise, 2017). Logger engines gather hits over time from different parts of the platform and display the activity as graphs and tables.

While EDM has a greater focus on methods at the intersection of machine learning, statistics, and database systems, LA puts a greater emphasis on human evaluation through visualization. The primacy of sight allows for effective visual analysis and, thus, enables users to draw conclusions by directly interacting with the visualizations (Keim, 2002).

Location analytics

Santos et al. (2014) used LA in analyzing learners' geographical positions to control the learning progress in real-time and had positive experiences. The monitoring in real-time and the potential to review the learning process based on geographical positions were seen as key activities of LBML teaching during and after the LBML activities. Therefore, a web service was built that automatically records the user's position, position accuracy, and username entity using the Geolocation API[17]. An interval period of eight seconds was deemed as the appropriate period required for data to be adequately interpreted. Due to the restrictions of the Geolocation API, data could only be collected when the learner was actively using the OMLETH-Player in the web browser.

Geoprivacy issues

Mobility data is among the most sensitive data currently collected using software and mobile phones. The position tracking of people is precarious because it affects not only privacy but also geoprivacy (by making the location known). Information about the personal location is highly dynamic and easily interpretable, even when a user is anonymized. Therefore, the cautious and secure usage of these datasets is essential to prevent possible abuse (Duckham & Kulik, 2006). For this reason, OMLETH users have been informed (through notifications) about geoprivacy before the login procedure. At this point, a learner could opt out of the tracking. Furthermore, the creators were reminded during the design process to inform their users of this issue in detail. Explorative studies were executed only with anonymized user accounts that were available for other teachers using the OMLETH-Creator as well.

[17] https://developer.mozilla.org/docs/Web/API/Geolocation_API (01.01.2020)

3.3.1.1.3 Server environment

To fulfill the long-term maintainability of the server environment, the system's software architecture required a distributed application structure that partitioned tasks or workloads between servers and clients. Servers provided maps and learning content as geographical data, and the system's clients requested the learning content as services.

State-of-the-art systems (see, in particular, Barak & Ziv (2013), Heimonen et al. (2013), Huizenga et al. (2009), Kohen-Vacs et al. (2012), and Santos et al. (2014)), used a GIS as three-tier architecture to divide between modules with different and independent functionalities. A three-tier architecture contains the presentation layer (client tier), the business logic (logic tier), and the data storage and resources access (data tier) (Fu, 2018). To communicate between clients and servers, Zurita & Baloian (2015) and Santos et al. (2014) used web map services for the place-based content (learning stations) with cloud computing. Cloud computing allows for web-based on-demand communication, with the business logic and the data hosted and serves from a database on the web (Yadav, 2014). It is a scalable, expandable, and almost perfectly elastic software service, and it enables ubiquitous, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) (Mell & Grance, 2011). Furthermore, the practical advantage offers by the service model Software-as-a-Service (SaaS), was that it requires minimal management effort and minimal interaction when deploying resources and applications, and extended access from anywhere through a web browser (Mell & Grance, 2011). Third, the public deployment model allows the use of several educational organizations.

Therefore, the managed public cloud ArcGIS Online[18], Esri's cloud-based mapping platform, was chosen as the backend for OMLETH. This program is accessible from web browsers and can host geographical data on virtual database servers (data tier). It is also able to control the manipulation of learning content through web services with georeferenced map features by GIS servers (logic tier). Furthermore, GIS servers deliver base maps with global coverage as georeferenced map images. The ArcGIS API for JavaScript 3.x[19] realizes the integration of the content and base maps of ArcGIS Online into the OMLETH applications. A managed cloud server at Metanet[20] hosts HTML5, CSS, and JavaScript files of OMLETH's applications. All data traffic between the clients and the server runs over a secure connection (HTTPS).

[18] https://developers.arcgis.com/ (01.01.2020)

[19] https://developers.arcgis.com/javascript/3/ (01.01.2020)

[20] https://www.metanet.ch/server/managed-server (01.01.2020)

3.3.1.2 Case study 1 with university students

3.3.1.2.1 Introduction and motivation

The first attempt to use LBML technology to support student learning during self-guided excursions was in 2015 and involved architectural students. The students were undertaking the architecture course "Theory of Urban Design: Learning from European Cities: for example Zurich" at ETH in the spring semester. The objective was to obtain feedback on how a lecturer prepares the LBML exercises using a reference example, and how the students perceive and master this specific example and the whole series of five events over the semester with OMLETH 1.0.

3.3.1.2.2 Methodology

Six students were enrolled in the architecture course. Using their mobile phones, the students sought to gain an understanding of the most significant urban planning theories and the complex interrelationships in the history of urban planning in Zurich by learning about the spatial and physical phenomena of the built city. The students' objective was to apply the theories of European case studies to local examples in Zurich, thus recognizing their relevance, temporal, and spatial difference, and local characteristics.

The course consisted of a series of ten sessions with five alternating topics. The sessions were first indoors, focusing on theory, then outdoors, with guided LBML exercises. All five LBML modules contained a fixed sequence of approximately 12 questions at different learning stations for a maximum duration of 90 minutes. The lecturer prepared the tour between seminars and the tour sessions to align the examples to the seminar's outcome and to include the current contexts on-site during the preparation.

The evaluation was undertaken using several methodologies. Participant observation of the lecturer during the preparation and implementation of a module, as well as direct observation of the students at an outdoor exercise as a reference example, formed the first part of the evaluation. The second part consisted of an open questionnaire for the students on their overall experiences regarding the learning effectiveness and usability of OMLETH at the end of the semester. These results, in combination with personal experiences during the whole semester, were shared by the lecturer in an unstructured interview at the end of the study.

3.3.1.2.3 Results and discussion

Preparation and planning of the LBML lesson

The lecturer had extensive experience in teaching non-technology guided tours. Despite having no experience in either the OMLETH system or the external LMS, he wanted to become immersed in digital teaching and to benefit from the scope of ETH's LMS. He was, therefore, open and wanting to link LMS activities with OMLETH (Figure 12 (a)). To transfer the classroom learning, he designed assignments about architectural artifacts as multiple-choice questions at 14 learning stations (Figure 12 (c)). Spatial reasoning was needed to analyze the historical situation through map analysis from a direct-linked web application[21]. The lecturer conducted two pre-tour preparation site visits to determine the content and locations. However, no final testing took place due to time restrictions. The total preparation workload was 17 hours and included the following work steps:

Step	Description	Workload in hours
1	An on-site inspection, a study of online maps, and the determination of the route three weeks before the exercise.	4
2	The creation of the learning content as forms in an LMS and external map services, and the construction of the learning stations' polygons in OMLETH one week before the exercise.	6
3	An on-site testing of the allocation of OMLETH's polygons.	1
4	The creation of the learning stations in OMLETH and the linking of the LMS forms to OMLETH's learning stations prior to the exercise.	3
5	An on-site testing of OMLETH's learning stations.	2
6	Adaptions of the learning stations in OMLETH.	1

Study execution

Direct observation was used to collect all results of the outdoor exercise. The exercise started on a bridge over the Limmat river in Zurich at learning station 0 (Figure 12 (c)). The students were introduced to the project and OMLETH technology and organized in three groups of two students each. In the beginning, the students complained about GPS positioning issues and stayed close to the class. After a couple of minutes

[21] https://omleth.ch/workshop/gta/B%C3%BCrkliplatz_SwipeMap/ (01.01.2020)

at learning station 2, the groups separated and conducted the remainder of the learning stations alone or in pairs without any significant technical issues. One student was unable to operate OMLETH due to her old first-generation smartphone. She teamed up with her colleague and was then able to participate. In the end, all of the students needed one hour more than planned to complete all 14 stations.

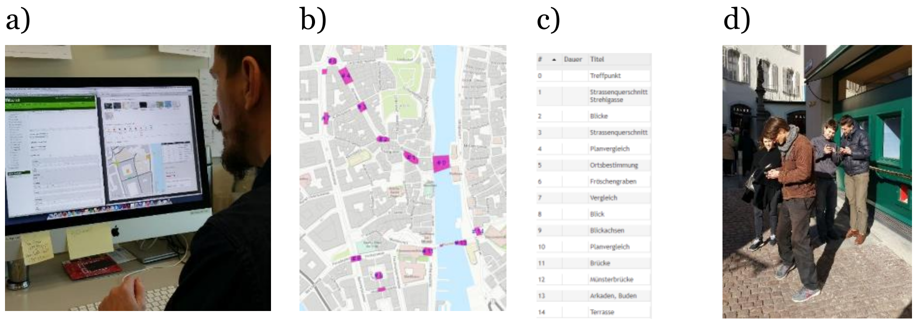


Figure 12 Illustrations of case study 1: (a) Lecturer preparing a module with the OMLETH-Creator and Moodle of ETH; (b) Map of the module; (c) 14 stations of the module; and, (d) A group of students at learning station 2

Feedback of the student focus group

The results of the student focus group were collected directly after the first tour to reflect on the learning process and any potential problems. Regarding usability, the students reported that OMLETH sometimes froze and crashed, that GPS positioning was poor, especially at the beginning of an exercise, and that the phones' batteries used a lot of power and were almost empty at the end of the tour. They, nevertheless, felt, in general, comfortable with the GUI and reported intuitive handling. However, regarding navigation, three of the six students wished that the position was displayed continuously and adjusted automatically, such as in different other map apps like Google Maps at that time when the user is moving. Regarding the design of the learning content, the students reported that some learning stations, the description or URLs to Moodle were missing. Thus the 100% completion of the tasks was partly not possible.

Overall feedback of the student focus group at the end of the semester

At the end of the semester, the students reported the experience of five visit exercises. They undertook a structured survey with open-ended answers to review and reflect the impact of OMLETH for the five exercises, including usability, satisfaction, and effectiveness.

Usability

Three of the six students who used modern mobile phones reported good usability. One further student replaced her old mobile phone with a new one and reported significantly better performance. The remaining two students reported a more frustrating than enriching experience in terms of the perception of the environment, due to technical problems. The screen size was an issue for them when they had to analyze and compare maps. The two students would have preferred to use large-sized paper maps over maps on mobile phones, a finding likewise reported in Santos et al.'s (2014) study. Regarding Moodle, the main issue for all participants was the downloading of the large pictures owing to bandwidth and network coverage limitations. Students found the small map display on wayfinding and orientation as challenging. They also found them cumbersome with the compulsion to press the learning station request button to receive a blue circle indicating the user's position. To reduce the zoom and pan interaction on the map, the students wanted a permanent display of their positions on the map, as offered by today's navigation applications such as Google Maps. Furthermore, students found the number of text entries with the virtual keyboard cumbersome. They suggested a replacement of long text instructions with audio or video presentations to reduce the tedious reading and scrolling interaction on small screens.

Satisfaction

The students appreciated the variety of the module, with seminar-room based theoretical learning combined with practical experience on the guided tours. In this, they noted the benefit and enjoyment of the situated approach of experiencing the theory directly and using Zurich as a local example. However, four of six students complained that they did not complete the entire module within the "given" lecture time or, if completed, needed 50% more time than scheduled. Students reported occasional missing links between the theory and the exercises in the city due to the lack of preparation, and not getting the full on-site benefit. In general, the students wanted more diversity between the individual learning stations. Regarding social learning, four of the six students preferred the individual and lecturer-independent explorations in small groups. By comparison, two students preferred the "classic" tour with the lecturer as a guide. One student, who preferred to work independently, was inspired by two field exercises where the lecturer was met halfway for a mini debriefing to discuss and reflect on the latest findings.

Effectiveness

All students made mention of the following points: 1) that the immediate visibility of urban planning facts provoked several ad-hoc questions; 2) that dimensions were easier to estimate because different perspectives could be taken; and, 3) that the learning object could be immersive, for instance, material like walls could be touched and analyzed at close range in comparison to illustrations and maps on PowerPoint presentations in the seminar room. One student reported a better understanding of the learning content and an awareness of previously unseen spaces being now visible. Each time the students returned to the locations of the modules weeks and days later while commuting, they were reminded of the visits and the most important aspects of the urban structures. With regard to the learning process, the lesson in the seminar room was very important. Describing the experiences and presenting the results were the core elements. The conversation was seen as essential, in terms of correcting the remaining misconceptions, as during the LBML tour, the web questionnaire's results did not provide further explanations for wrong answers and were not comparable amongst all students. The lack of exchange and feedback on-site was reported as the biggest issue, not only cognitively but also motivationally.

Results review and discussion with the lecturer

The last step of this case study was an unstructured interview with the teacher. He reviewed the student results and supplemented them with personal findings. He reported that he missed a certain willingness to be surprised and to discover and engage in new content. He concluded that students needed greater agency to better learn about and converse on the topic. Regarding the structure and didactics, he considered a re-design of the didactical concept for the future semester that fosters active learning. Therefore, he requested a tool that facilitates the process of data collection and makes it possible to collect specific, structured information in a systematic way that can be compared among students in the field. He also concluded that future activities must have more diverse methodological approaches and that the mode of instructions should be varied. Assuming a higher workload, he asked for some technical improvements regarding the OMLETH-Creator to facilitate the creation of the designs. First, to avoid tedious, repetitive work of copy/paste when new modules contain similar content, he requested a feature that allowed existing modules to be reused. Second, he requested a tool to assist the scheduling of learning stations in addressing the issue of readings regularly underestimation distances between stations. Third, to avoid incomplete text entries, such as task descriptions or URLs to external services, he called for a better overall view of the text content to check whether the information is complete and correct promptly.

3.3.1.2.4 Technical design findings

Based on the results of direct observation, participant observation, focus group interviews, and students' and lecturer's feedback at the end of the semester, the findings on the technical design of OMLETH 1.0 are summarized as follows:

F3.1.1 Improvement regarding the usability and performance (crash or freeze) of the OMLETH-Player is needed, and the user's position should be displayed continuously and adjusted automatically when the user is moving.

F3.1.2 A function is required that allows the reuse of modules by duplication.

F3.1.3 A feature is required that allows estimating the total time needed to use a module based on the walking time and the time spent at the learning stations.

F3.1.4 A feature is required that allows viewing the learning stations' content in a tabular view.

In addition to these findings, the experiences revealed that further requirements are needed with regard to teaching, learning, and technology. To cope with LBML lessons in preparation and execution in real-time on-site, teachers must have excellent skills in didactics, spatial knowledge, organization (time management), computer literacy, agility, flexibility, and creativity. The contextual challenges that concern the teaching preparation were summarized in Sailer et al. (2015), and, a didactic planning framework to plan LBML activities for education and game scenarios were published in Schito et al. (2015). Learners' computer literacy concerns the requirements of technical knowledge of the mobile phone and GPS positioning in the mobile browser to handle basic and recurring issues. The last finding concerns student comments regarding the need for permanent teacher feedback and questioning capabilities during the inquiry.

3.3.1.2.5 Summary and conclusion

This design research analyzed how a lecturer prepares LBML exercises using a reference example and how students perceive and master this example and the whole series related to OMLETH 1.0. The need to improve the usability and performance of the technology was identified to facilitate the planning and implementation of LBML units for teachers with features, such as a route planner, a tabular view of the contents, and a web app for location-based multimedia documentation. Based on the results, it was recognized that teaching LBML requires multiple advanced abilities to achieve high-quality LBML designs. Furthermore, students need basic technical knowledge of mobile phones, clear organizational, educational, and technical instructions. There is also a need for communicative relatedness between teachers and students to engage in and foster better learning in the field.

3.3.1.3 Case study 2 about map-based visual analytics

3.3.1.3.1 Introduction and motivation

In the summer of 2015, a second case study was conducted using LBML technology. The participants were adolescents and two teachers who designed the LBML activity as an introduction trail for the science camp "Swiss GeOlymp22 science week" at Jurapark Aargau. The motivation of the study was to obtain feedback from the teachers on whether the map-based LA support was able to detect and interpret spatiotemporal patterns and irregularities in the trajectories of both single and multiple learners. The results were analyzed in Sailer et al. (2016) to determine how these visualizations help from the research perspective and contribute to a better understanding of the learning sessions.

3.3.1.3.2 Methodology

Two teachers and 15 students were enrolled in the LBML activity. The teachers prepared the trail as an introductory event with facts and figures, and the students received an overview of the rural site to assist in locating the seven learning stations in a predefined linear order. The students were introduced to the OMLETH-Player web app, the functionality of GPS, and the appropriate handling of the web app's positioning feature.

Several instruments were used to carry out the study. The web app was configured to collect the students' positions at intervals of one second, a questionnaire was used to gather the students' overall experiences regarding satisfaction and usability (GPS positioning) of the technology, and an unstructured interview about the potential of the analytics of the students' data was conducted with the two teachers.

3.3.1.3.3 Results and discussion

The participants reported a positive experience with OMLETH, with 12 students stating they would play another module. The participants brought their mobile phones, which were not more than two years old. Two students reported positioning issues, mainly in the first part of the round trip. The students' positioning data was presented in an unstructured interview with the two teachers at the end of the study to analyze the data and derive important insights. The analysis was divided into three steps.

Analytics of single learners' movement

Step 1 contained the presentation of the position data on a 2D map as collections of point representations of two learners (learner A and B) visualized in Figure 13. The teachers reported that at first glance, the learners accomplished the tour as intended. The tour was designed along a trail path. The trajectories between learning stations 1 and 4 of learners

[22] https://science.olympiad.ch/en/ (01.01.2020)

A and B fit well to the path represented on the map. The teachers, therefore, assumed that the combination of map-reading and wayfinding was not particularly challenging at the beginning of the field trip because it followed the route. This, however, changed after learning station 4, where an intersection required the learners to make an active decision. Learner A took the left and short path to learning station 5, while learner B took the path to the right at the junction, which led to a detour. The teacher reported that it was important to be aware that Learner B did not cross the farm between stations 4 and 5, and therefore did not experience an example of a typical farm of the region. This finding would allow the teachers to put extra stations at the farm's location to ensure that everyone gained a brief impression.

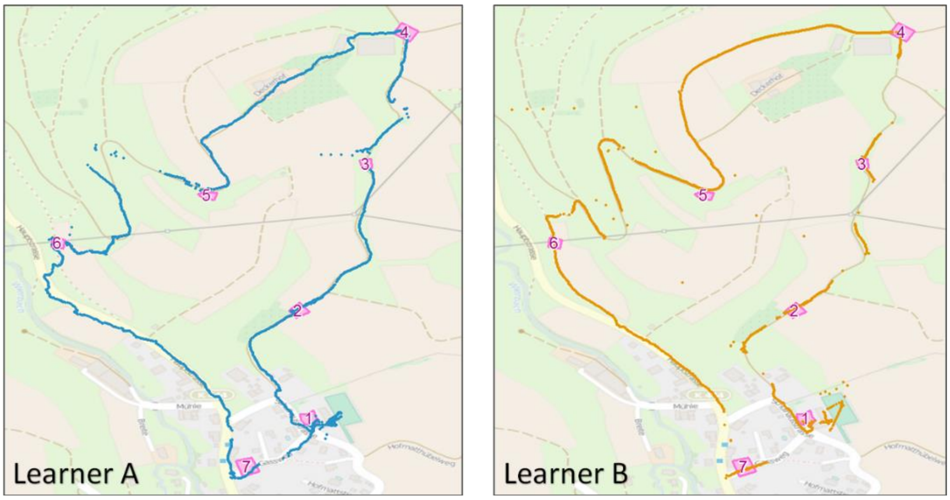


Figure 13 Trajectories of two single learners' activity (left) Learner A and (right) Learner B executing a field trip are visualized as two single-colored point clouds on 2D maps. The learning stations are numbered and marked with pink polygons. (Software: © ArcGIS for Desktop 10.3, Esri; base map: © OSM)

Analysis of special features

A particular finding discussed in Sailer et al. (2016) was the zig-zag-like path of learner A from learning station 6 to the main road underneath. This was assumed to be an issue in wayfinding, or a hiking-typical behavior when tackling steep slopes. The teachers, who had local knowledge, evaluated these findings as speculations and did not spend significant effort on these details. The gaps in both trajectories were moments in time for which no data is available, as was discussed in Sailer et al. (2016). The causes of these gaps can be manifold. Either OMLETH-Player crashed or froze, and the data transfer stopped, or the students temporarily switched to another app, and the Geolocation API stopped recording data. Due to this ambiguity, teachers recognized the limitations on the interpretability of passively recorded movement trajectories.

Visual analytics in 3D

Step 2 was a visualization in 3D, described as a space-time cube. Figure 14 shows a space-time cube from two perspectives, in a three-dimensional representation and an underlying map. The two horizontal dimensions represent the spatial extent, and the vertical dimension visualizes the course of time. The temporal axis is oriented from the bottom to the top, starting from the first space-time position. Speed can be detected as the slope of the movement track in the space-time cube (G. Andrienko et al., 2013). The teachers analyzed the cube by moving, zooming, and rotating it, and observed findings similar to those described above for the 2D representation. These findings included counterclockwise movement, no long stops, and breaks between the stations at the same walking speed. The rule is that the steeper the track, the slower the pace of the walking subject. Long vertical line segments inside the learning stations may indicate a prolonged occupation with the task. The teachers evaluated the 3D visualization and recognized the potential to gain, at a glance, a quick overview of the whole LBML unit. However, regarding the usability, navigation around the elevated tracks in a 3D software environment was technically challenging and required higher-order spatial thinking skills.

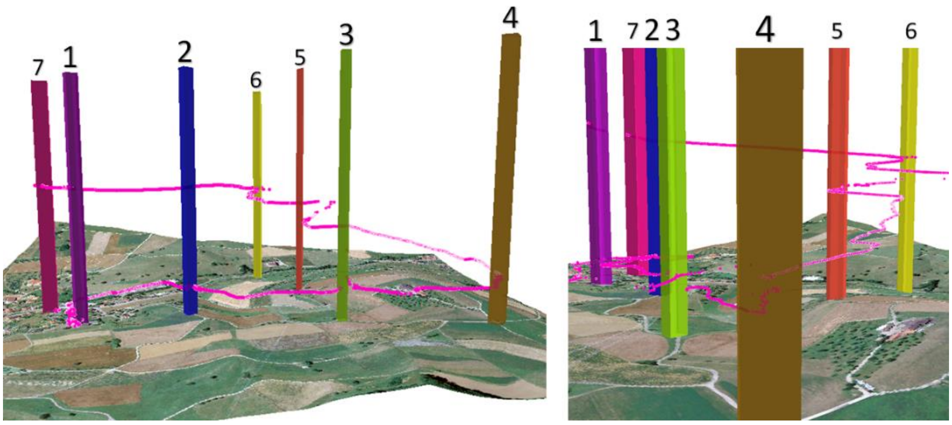


Figure 14 Trajectory of a single learner's activity: (left) full extent; and (right) zoomed extent inside learning unit 4) is visualized in a space-time cube. Delimited areas containing learning stations are numbered and extruded in 3D. (Software: © ArcScene 9.3, Esri; base map: © swisstopo)

Analytics of Multiple Learners' Movement

Step 3 was a visualization in 2D and 3D of all students together. The map identifies the users who show similar movement patterns (e.g., Yuan and Raubal 2014) and, based on these similarities, detect clusters of the same behavior.

Figure 15 (left) shows learners' trajectories in an interactive 2D map distinguished by colors, where the individual paths could be switched on and off. The teachers recognized that the educational setting of the sequenced arrangement, in combination with the road, resulted in a pattern of similar trajectories. The point discussed in Step 1 (about the route decision after learning station 4) revealed that several groups did not pass the farm, which would have had consequences for the debriefing procedure. Therefore, having this information during the debriefing would lead to a more detailed discussion and provide the opportunity to screen and analyze particular situations. The discussed zig-zag path of learner A (blue in Figure 15 (left)) showed the most differences when visually compared with the others. The almost regularly dotted straight lines represent the pattern of GPS measurement errors that occurred during the process of searching for GPS satellites. If a complete or partial loss of satellite signals occurs, so-called Kalman filters based on the principle of recursive state estimation are used to predict the most likely position of new points based on previously recorded points and their statistical noise (Hofmann-Wellenhof, Lichtenegger, & Wasle, 2007). Thus, such points are statistical estimates and are often represented as linear patterns indicating temporary violent positioning problems.

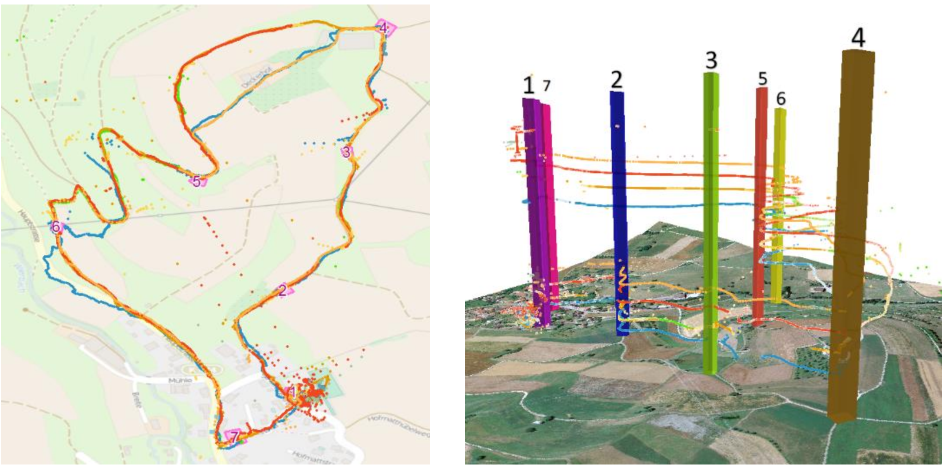


Figure 15 Several trajectories of learners' activity differentiated by colors: (left) as point clouds on a static 2D map; and, (right) in a space-time cube where the delimited areas containing learning stations are numbered and extruded to 3D. (Software: © ArcGIS for Desktop 10.3 © ArcScene 10.3, Esri; base map: © OSM, swisstopo)

Visual 3D map analysis of multiple learners

Figure 15 (right) shows learner's trajectories in a space-time cube distinguished by colors. The parallel paths reveal that the learners walked with similar velocities and were at the same positions, but not at the same time, and were therefore spatially not related. In contrast, tangent or intersecting lines show that learners potentially met and talked to each other because they were at the same place at the same time. Both teachers reported that the high added value of this presentation was that the whole event could be grasped at a glance, and potential collaboration and conversation could be extracted. They noted, however, that with larger school classes and, thus, more substantial data, it would likely not be possible to distinguish between individual trajectories. Therefore, a combination of 2D and 3D visualizations are necessary to ensure an in-depth analysis even with many students.

3.3.1.3.4 Technical design findings

Based on the results of the lecturer's feedback, the findings on the technical design of OMLETH 1.0 are summarized as follows:

F3.2.1 The map-based visual analysis was helpful in terms of analyzing LBML activities to gain insights into the learning activity and to identify the potential technical and orientation problems of the learners.

F3.2.2 The integration with OMLETH with an intuitive visual representation and navigation in the 2D and 3D maps is useful for allowing more focus on the local details of the contexts during the debriefing.

In addition to these points, further findings are recognized and important to note. Map-based visual analytics can support an in-depth analysis of the LBML learning process over the entire teaching process. They achieve this by: supporting learners with prompt scaffolding during the activity; recalling specific situational contexts with data-based evidence during debriefings; and, allowing for a review of the history of the event during the redesign of the module. However, the case study showed that using the analysis for the first time, especially in 3D, was a cognitive challenge and required not only basic GIS experience but also strong spatial thinking skills.

3.3.1.3.5 Summary and conclusion

This case study analyzed how teachers evaluate the map-based visual analytics of LBML movement trajectories for a reference example. Several benefits were identified, such as insights into the learning process, orientation problems of learners and potential technical problems of the mobile equipment used. The results revealed that map-based visual analytics benefits the execution, debriefing, and design adjustments for the follow-up activity. In Sailer et al. (2016), directions in the research of web-based visual analytics with interactive maps were determined to achieve data-driven analysis beyond traditional LA of LMS with time as the independent variable.

3.3.2 Second design and case study

This section presents the design and implementation of the second solution based on the enhancement requests of the first two case studies. The goal was to improve a set of functionalities and usability. Section 3.3.2.1 presents the key features of OMLETH 2.0 with the application of suggestions made in Sailer et al. (2016). The illustrations are displayed in "what's new in OMLETH 2.0"[23].

The testing involved a case study with students from the Department of Architecture at ETH Zurich (Section 3.3.2.2). Recruiting these students for the study a second time allowed this research to benefit from a comparison between similar settings.

3.3.2.1 System design of OMLETH 2.0

The purpose of the design adjustments was to reduce complexity and the number of clicks for specific tasks in OMLETH's clients. In this, the intention was to improve usability and performance. The architecture with the data tier and the logic tier was not changed. The frontend remained composed of two main applications, where the OMLETH-Creator (Section 3.3.2.1.1) received major enhancements in functionality and usability, and the OMLETH -Player (Section 3.3.2.1.2) received major enhancements, mainly in usability.

3.3.2.1.1 OMLETH-Creator

The GUI of the OMLETH-Creator was rearranged to improve usability, and it featured several new tools requested in the two case studies. The first improvement addressed finding F3.1.4, where teachers less familiar with digital teaching needed suggestions for productivity, survey, and multimedia tools. A catalog of external web and mobile applications, including video tutorials on OMLETH's website[24], closed this gap. The second feature allowed the duplication of personal modules to prevent the repetitive work of copying/pasting existing content (F3.1.2). The third improvement addressed the finding F3.1.3, to assist the temporal organization of a teacher-regulated activity. The system should be able to calculate a potential route to estimate the module's time frame, including the time required for the use of the learning stations. Accordingly, the class of the learning stations was provided a duration option, which detailed the expected time use at each station. A route planner was added to calculate the walking time based on the route length, with a setting for walking speed between 2 and 8 km/h. The subtotals and the total time could be directly updated when teachers were creating modules. The route

[23] https://omleth.ch/version/2/Whatsnew_Omleth2.pdf (01.01.2020)

[24] https://omleth.ch/version/2/lernvideos.html (01.01.2020)

of the route planner was not made available to the OMLETH Player in order not to further restrict spatial thinking processes, such as orientation and wayfinding, between two stations. The fourth feature addressed finding **F3.1.4**, in so far that creators required a better overview of the module's content to check the content for completeness and correctness effectively. To overcome this, a full-screen tabular representation, also known as an attribute table, of the created learning stations, was developed. The individual items were displayed in columns and, therefore, were easily comparable with each other. Additionally, an integrated sorting functionality improved the usability of this attribute table. The module and learning station could be linked to external services (web app) to embed any kind of multimedia services, or to refer to URL-linked productivity tools, such as diary-like location-based multimedia documentation (**F3.1.5)**. The fifth feature addressed the findings of the second case study that focused on the potential of map-based LA in LBML (**F3.2.1**), which indicated the need for a viewer that could visualize learners' trajectories. Subsequently, an integrated GUI for visual analytics (VA) in OMLETH-Creator was developed that contained a map interface to include the learning stations, the multimedia collectors, and the planned route. Through this interface, data automatically updated the movement trajectories of the learners using the OMLETH-Player. To gain further experience and to ensure the analysis was easy to use and intuitive (**F3.2.2**), the map viewer solution was developed only as a 2D representation.

3.3.2.1.2 OMLETH-Player

The OMLETH-Player 2.0 contained considerable improvements in performance and usability, with new functionalities and design adjustments to the GUI regarding the main request of finding **F3.1.1**. Figure 16 (left picture) represents an example of the beginning of a module. The new iFrame capability allowed the embedding of any multimedia content from external systems and services, such as audio or video content.

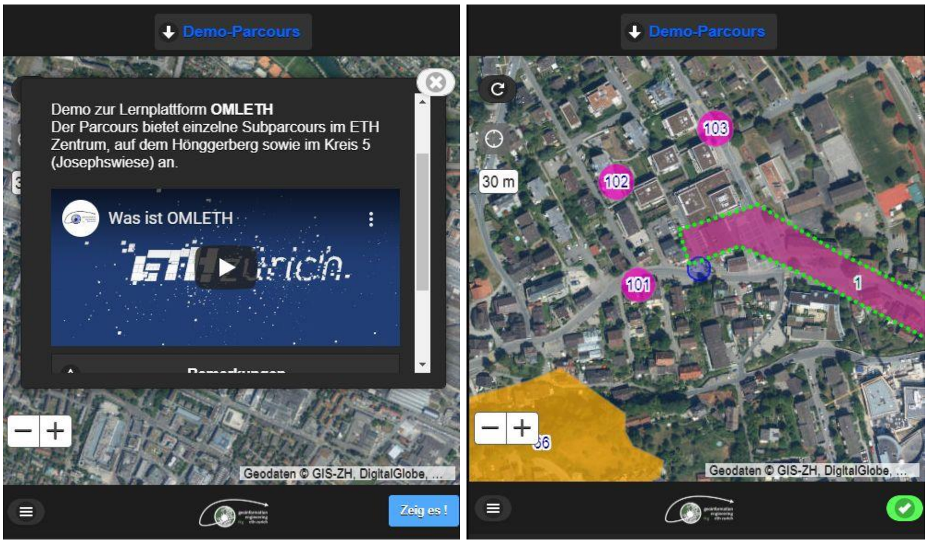


Figure 16 OMLETH-Player 2.0: (left) Module introduction with embedded multimedia web resources (example with YouTube); and, (right) Module map view after a completed activity at learning station 1 (green dashed outline).

The Player's design was improved by removing or rearranging the buttons according to the zone for thumb movement in the corner space of the display (Yu, Huang, Hsu, & Hung, 2013). The Learning station request button, featuring a blue icon with "Zeig es!" appeared at the bottom right corner in the footer bar, at the closest point to the user's right-hand thumb. After the user pressed the button, the learning content was displayed directly in a pop-up window when the device detected that the user was within the area of a learning station.

Performance issues, such as crashing and freezing (**F3.1.1**), were solved by refactoring the source code and by developing a "Reload button", displayed as a sweeping arrow in the top left corner. This button reloaded the whole web page according to the last configuration of the module and map extent. Map navigation requests, which provide the user with the capability to geolocate without a manual learning station request (**F3.1.1**), were solved with the "Geolocation button" displayed as a crosshairs icon that appeared in the top left corner of the map below the Reload button. After the geolocation button was pressed, the user's position was continuously displayed in the center of the map and automatically adjusted as the user moved. Independent of this tracking functionality, the player collected position data every eight seconds when the web application was in active use with the consequence, as soon as the user temporarily opened another browser window or app, no further data could be collected.

To improve the understanding of GPS and behavior in case of poor quality further, such as when moving instead of standing still, the horizontal accuracy value indicated the quality of positioning in the "Horizontal accuracy display". The horizontal accuracy value is a statistical estimate of how close the reported locations are to the ground truth, expressed as distance radius plus confidence interval in meters (Brimicombe & Li, 2009). The display updated the accuracy value when the Geolocation API gathered a new position through a combination of sources (GPS, Wi-Fi triangulation, IP geolocation, and cell tower triangulation).

3.3.2.2 Case study 3 with university students

In the spring semester 2016, the architecture course "Theory of Urban Design: Learning from European Cities: for example Zurich" again offered to participate in a case study to examine students' learning on self-guided excursions. The objective was to observe how new students would conduct the same LBML exercises as in 2015 on a reference example, with new didactical approaches that increase learner's agency and engage several senses, new technology such as OMLETH 2.0, and ETH's material online archive. Furthermore, the investigations of the case study included the part of learning analytics in how the lecturer dealt with the new 2D viewer to analyze the learning process during the execution and to review the activity during the debriefing in the seminar room.

3.3.2.2.1 Methodology

Twelve students enrolled in the course. The primary objective was for the students to analyze complex geographical and temporal interrelationships. The secondary objective was the recognition of urban ensembles, patterns, and configurations by gathering reference examples and patterns of urban development history using mobile technology.

The course procedure was the same as in 2015 (see Section 3.3.1.2.2). The exercises were didactically revised with more constructivist approaches. The students had to actively discover the architectural patterns by researching ETH's material archive[25] and mobile GIS technics in small groups.

The evaluation was conducted through both direct observation on a reference example and participant observation of the lecturer during the preparation, the on-site exercise, and the debriefing on the example. The goal was to examine the entire teaching process and compare the results with Case Study 1 through an unstructured interview with the lecturer.

[25] http://www.materialarchiv.ch/cms/de/sammlungen.html (01.01.2020)

3.3.2.2.2 Results and discussion

Planning and preparation of the LBML lesson

In this case study, the lecturer had experience from the ten LBML events previously undertaken (in the first case study in 2015) and, subsequently, commenced the lesson preparation earlier than the year before. The goal was more action in terms of physical movement, conversation, and multimodal reasoning. Inspired by Bruner's (1961) theory *The Act of Discovery*, the lecturer introduced well-structured problem-solving tasks (Aebli, 1983) and the jigsaw technique (Aronson, 1978) to foster cooperative learning, and a messaging app to conduct an online debate. The tasks were enriched by the material of the ETH Building Library for Materials (Material archive) as multimedia web services. The lecturer, therefore, collaborated with experts that could show him the collection and suggest specific material. One of the learning goals was that theories of settlement structure patterns had to be understood, and relationships had to be deduced. Therefore, the learning procedures included the use of spatial concepts, spatial representations, and spatial reasoning to solve tasks. This included the analysis of historical maps with new maps and the surroundings and the collection of location-based data. The data were collected using an app that allowed location-based multimedia documentation, which is well-known in the field of mobile GIS. One of the learning tasks involving spatial reasoning was a collaborative online debate about constructing interpretations of the layout of individual buildings (facade structures) based on different physical perspectives. The goal was the promotion of the exact articulation and use of language to describe an architectural phenomenon and the conclusion that the buildings have different structures depending on the exposition, based on urban planning theories. As the new teaching approaches required significant brainstorming, the total workload of the preparation took eleven hours, and included the following steps:

Step	Description	Workload in hours
1	An expert meeting with ETH Building Library for Materials, on-site inspection and brainstorming the technical and pedagogical approach, and the study of online maps six weeks before the exercise.	2
2	The determination of the learning stations' locations and the linking of the external web apps and content to OMLETH's learning stations a week before the exercise.	6
3	On-site testing of OMLETH's learning stations.	2.5
4	Adaptions of the learning stations in OMLETH.	0.5

Study execution

The method of direct observation was used to collect the results of this reference example. In groups of two or three, the students took different roles in tackling the exercise. Therefore, only eight of the 12 students used the OMLETH-Player, while others had the task of exchanging their observations online with peer groups over the embedded messaging service. Figure 17 shows a group of students attempting to solve a cooperative designed task. This sample task included a short introduction about how the surrounding buildings had developed over the previous 200 years. This included information on the spatial arrangement of the buildings, their typical visual characteristics, the original building elements, and the elements that were missing. These missing elements needed to be investigated, assisted by an external web that contained interactive maps.

Figure 17 Tour on March 11, 2016, in the Riedtli neighborhood with a snapshot of a student group executing the task at station 4, requiring them to seek artifacts along the house facades in the immediate surroundings.

Map analysis

Figure 18 depicts the graphical interface of the web app, including an overlaid historical map that the user can swipe to compare the past and current surroundings of the area. This task required skills such as map reading, spatial perception, and imagination to search for the missing elements, and spatial reasoning to recognize spatial patterns and relationships. It also required cognitive skills to recall the architectural taxonomies that were taught in the seminar room.

Online debate

Another task involved online debate between the students' groups and was about linking theories to the layout of individual buildings. This task needed to be conducted simultaneously by all groups of students at different locations. Therefore, the groups needed to be allocated to distinct locations around the building. The lecturer helped with the organization of the allocation through the inspection of the learner's position. For this, the lecturer used the OMLETH 2D Viewer and gave commands via the messaging app. Once the groups were ready, the lecturer asked questions through the messaging app to launch the debate. The students sent their group-based interpretations by attaching images together with text explanations. The lecturer decreased the intervening questioning and followed the debate remotely and passively. Regarding individual feedback to answer remaining questions, the lecturer's concept was to respond to the first two or three incoming questions with detailed explanations until the incoming questions were repeated. At this point, to counter his messaging workload, he posted an elaborated student example in the general chat and solved the issue with the help of the example feedback.

Figure 18 Web application with map comparison analytics: A map service that contains historical map information with swipe functionality[26].

Classifying objects

The integration of ETH's material archive was varied with two didactical approaches. The first approach relied on the cognitive apprenticeship model of Collins et al. (1988). Here, students were presented online with the material information to observe the properties of the material and its classification procedure. After that, students began to solve the task of mapping objects, such as the facades of the building entrances to the online material. The lecturer initially provided transitional support (scaffolding) with facts through individual coaching using the integrated online messenger. The lecturer then gradually withdrew this support after the second or third task.

In the second approach of the integration of ETH's material archive, the students received a well-structured problem using the PADUA-scheme of Aebli (1983) (see Section 2.4.2.1). The goal was to find and identify relics of the door and facade design from previous decades that could be determined based on a specific architectural theory.

[26] https://omleth.ch/workshop/gta/Unterstrass_SwipeMap/ (01.01.2020)

For the survey, students had to download an app that facilitated the process of data collection, by a given data input structure. Figure 19 depicts the map view of the mobile app containing the students' results of the gathered observation. The colored areas represent the areas where groups where allocated in order to obtain results that cover as many areas as possible, which are then analyzed in the debriefing. The lecturer designed the data fields and the data input structure. The performance of the students was to recognize and determine the objects. The task was of a cooperative nature and required several tasks to be performed simultaneously. One person was responsible for research in the material archives. Someone searched for the physical characteristics of the relics and a third person mapped the observation in the mobile app. A fourth person reported special findings in the group chat. For the identification of the relics surfaces such as plaster, stone, and wood, the students showed a multi-stage and multimodal learning approach. Some students classified the examined material surface into a superordinate material group. Other students accurately determined the used material.

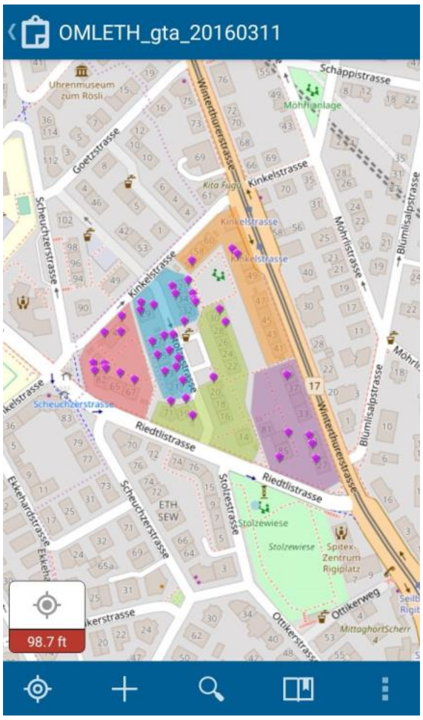


Figure 19 A mobile app that enables the collection of location-based data

(Software: © Esri's Collector for ArcGIS)

The mapping task concerned not only the visual senses but also the haptic, such as climbing stairs and touching handrails or surfaces. The aim of this task was to present the artifacts in a multimodal way to let students get creative and memorize the experiences in a sustainable way. By doing so, students would then be able to apply practical knowledge to new theories, which they acquire in the seminar room. The app assisted data collection with automatic georeferencing, whereby the location could also be set manually. The data was stored on ArcGIS Online, the same backend of the GIS servers of OMLETH, and is displayed as a point feature on the map. The application was configured to allow students to view and access all the collected data at the same time.

The debriefing took place one week later with the assistance of the OMLETH-2D-Viewer (see Figure 20). The lecturer used the 2D Viewer to structure and assist with the discussion, and each group had to present their experiences and findings. The viewer allowed both the students and lecturer to address specific details that the students might have explicitly experienced on their route. This led to a profound and intensive discussion. A semester-end discussion in the seminar room showed that the students could still recall the events and explain the theories by using examples of individual events.

Figure 20 OMLETH-Creator data viewer GUI to analyze the selected trajectories of Learner 01 and Learner 02 (Group 1).

Results review and discussion with the lecturer

In an unstructured interview at the end of the semester, the lecturer reviewed the reference example and the other examples by comparing them with case study 1. Regarding the preparation workload, he used the possibility of duplicating a module and adapting the existing material, and thus, saved a lot of time. Due to the intensive involvement with experts from the material archive, he would have liked to create the OMLETH module in collaboration with them. The number of applications of new tools showed that the workload for creating the new applications remained high. In the beginning, with the integration of the material archive content, the workload per module required more than ten hours of work, and then an average of eight hours per module thereafter.

Concerning pedagogical achievement, the lecturer found the shift from pure reproduction learning (see case study 1 in Section 3.3.1.2) to constructivist learning with the increased agency for the learners as beneficial. He also deemed collaborative and structured inquiry learning with multimodal approaches and the use of collaborative mapping tools and the messenger app worthwhile. The students showed higher engagement than in case study 1 and a positive attitude during the entire procedure of the projects, including the debriefings. Some students appreciated the approach of the cognitive apprenticeship model because of the direct link to the lecturer through the digital chat for feedback, questions, and knowledge exchange. Other students disliked the use of online chats and preferred face-to-face interaction with the lecturer. Overall, the lecturer concluded that the constructivist approach led to a higher number of discoveries, findings, and opinions of the learning content. In particular, the debriefing of the reference example of this section resulted in constructive debate and in-depth discussion.

The OMLETH-2D-Viewer as a teaching tool for tracking students in real-time was very helpful in the example of geographical group allocation for group discussion and would not have been possible without it. Furthermore, the map-based visualizations of learner's movement trajectories and the recorded communication history with the messenger app across the entire event cultivated rich debriefing sessions. These debriefings provided a platform for individual group narratives related to concrete situations on site thanks to the reminder function of the trajectories. The lecturer did, however, refer to the difficulty of conducting temporal interpretation with large amounts of point data, in regards to the visual analytics of the trajectories. The 2D perspective of the map viewer was limited in providing insights about the location of both long and short student delays. He noted that open investigations, including free exploration and criss-cross movement, would be potentially impossible to distinguish the spatio-temporal relationships of individual learners. The 2D view is not sufficient to identify patterns of relatedness or to extract problems regarding wayfinding and active use of the web application.

Concerning the performance of the OMLETH Player, the lecturer reported that the students had fewer problems in handling the web browser and the device compared to the first case study. He suggested that the reasons for these improvements were adaptions such as better teaching instruction, newer mobile phones, and usability improvements to the web app, including the location accuracy display indicating issues with GPS. The lecturer, therefore, drew, in comparison to case study 1, a much better conclusion regarding quality, due to both pedagogical and technical improvements.

3.3.2.2.3 Technical design findings

Based on the results of direct observations and participant observations, the findings on the technical design of OMLETH 2.0 are summarized as follows:

F3.3.1 In regards to the free exploration or open inquiry scenario, the 2D Viewer showed limitations in providing insights about the social learning activities and for obtaining information about the active use of the web app while navigating to the learning stations.

F3.3.2 To deepen the learning process, students should be able to access and analyze the personal data (user interactions and the movement trajectories) acquired through the system. This would allow them to recapitulate the learning process and would assist them in the memorization of the experiences in situ using cognitive mapping.

F3.3.3 A feature is required that would allow a straightforward approach to co-authoring and the sharing of modules with other creators.

Another finding was that the OMLETH player meets the overarching requirement for an easy-to-use technology under the conditions of a good introduction. The handling of OMLETH in connection with external services and mobile apps worked well and enriched the methodological possibilities of LBML.

3.3.2.2.4 Summary and conclusion

This case study investigated how a lecturer prepared and conducted a new LBML exercise based on the experience of implementing and conducting a previous one. In particular, the modifications in didactics and technologies were examined in a reference example. Direct observations revealed how students reacted to these didactical changes and mastered the new technical challenges of (and improvements to), OMLETH 2.0, and how they responded to the introduction of new web apps and mobile apps from the GIS field.

The change from pure lecturer-led inquiries to inquiries including students' agency to engage self-regulated and multimodal learning, could be concluded as successful. With the rich debriefing, including several links to data analysis (movement, communication, and documentation), the LBML activity transformed into well-structured project-based learning activities. Some limitations nevertheless called for improvement. A demand for further information about when and where users actively interact with the OMLETH-Player and 3D-Viewer was identified to analyze social learning activities, such as spontaneous meetings where face-to-face conversations may have taken place. Furthermore, the LA interfaces with 2D and 3D map contexts need to be accessible for learners, so that they can review the LBML activities independently of the teacher-led review session. Based on the results of this case study, the proposed research directions of Sailer et al. (2016) for map-based visual analytics in 2D and 3D for LA in LBML activities can be confirmed. Regarding lecturer's workload, the positive efforts had the disadvantage that the workload was not reduced by extensive and multi-faceted preparation.

3.3.3 Third design and preliminary study

This section presents the research-based design and the implementation of the third solution based on the enhancement requests of the third case study. The goal was to improve the usability of the OMLETH-Creator and Player and to embed the data analytics viewer as a separate application in the OMLETH system. This would allow the analysis of movement trajectories by both teachers and learners. Section 3.3.3.1 presents the key features of OMLETH 3.0[27]. The illustrations are shown in "what's new OMLETH 3.0"[28]. Section 3.3.3.2 outlines the study procedure for a long-term comparative study at a vocational school. The outcome of the case study with the vocational school had the primary objective of validating an experimental design and the robustness of OMLETH to ensure the execution of an experimental study with a large sample presented in Chapter 4.

3.3.3.1 System design of OMLETH 3.0

The purpose of embedding the 3D viewer and isolating the 2D and 3D viewer in a separate application was to allow learners to review the activities and access the learning content independent of a teacher debriefing. Section 3.3.2.1.1 presents the OMLETH-Viewer, including map GUIs, in 2D and 3D, for analyzing the movement trajectories. Section 3.3.2.1.2 discusses the sharing and collaboration capabilities of the OMLETH-Creator, and Section 3.3.3.1.3 describes minor changes in the usability to increase the spatial awareness of the user.

3.3.3.1.1 OMLETH-Viewer

OMLETH-Viewer is a new client, separate from the OMLETH-Creator and OMLETH-Player, which was proposed in finding **F3.3.2.** It provides LA and enables both teachers and learners to review movement trajectories independently of a teacher's debriefing. The aim was for viewers to have the capability to discover information and social connections and to predict and advise on learning as suggested by Siemens and Baker (2012). The OMLETH-Viewer included a combination of the 2D and 3D map viewer, which, owing to the highly sensitive nature of the location data, were made accessible only to the users that played the module with the OMLETH Player.

The 2D Viewer was intended to meet the remaining requirements necessary to enable a complete technology-based approach to the LBML process, including preparation, execution, and debriefing. Compared with OMLETH 1.0, the 2D Viewer in the new client received an additional

[27] https://omleth.ch/version/3 (01.01.2020)

[28] https://omleth.ch/version/3/Whatsnew_Omleth3.pdf (01.01.2020)

dataset of the recordings of the user interactions through click events related to the learning request button (**F3.2.2**). The user data was therefore divided into two trajectories: the movement trajectories of the passively collected positions and the trajectory of the click events of the learning station request. Both layers are displayed in real-time and are differentiated by colors to represent the users. Thus, the map-based visual analysis allows the investigation of the learning activity owing to the two trajectories in combination with access to the learning stations, the multimedia collectors, and the planned route of the creator, as well as the possible use of multiple base maps.

The 3D Viewer was intended to compensate for the limitations of the 2D Viewer (**F3.2.1)**. It enabled an analysis of the sum of the point clouds of the passively collected movement trajectories at a glance. Also, it allowed the user to search for spatio-temporal relationships that could relate to social learning moments. The 3D approach was implemented with the desktop software of case study 2 (see Section 3.3.1.3) on the web. The 3D Viewer required a 3D GIS engine on the web, and, therefore, utilized the ArcGIS API for JavaScript 4.x[29].

3.3.3.1.2 OMLETH-Creator

OMLETH-Creator was redesigned to provide a better experience and align the overarching goal of ease of use. This was in response to findings in case study 2, which showed that teaching quality depended on the tool the teachers worked with. Co-authoring was requested as a finding (**F3.3.3**) and has become a trend thanks to the connectedness through the web. Co-authoring of teaching material enables the fast and easy exchange to develop creative learning design (Magoulas et al., 2009). It was also recommended in the LBML context by Santos et al. (2014) and Tiitinen (2015). The co-authoring in OMLETH was implemented in a way that students could theoretically develop an LBML activity as well (see future work in Section 6.2).

3.3.3.1.3 OMLETH-Player

OMLETH-Player 2.0 contained a slight improvement in usability and new background processing. Finding **F3.2.2** suggested that the positions and number of the click events of the learning request button could indicate how students perceive usability regarding positioning. The assumption was that the higher the number of requests for access, the lower the satisfaction, which is investigated in the main study in Chapter 4. Therefore, OMLETH-Player records these click events in addition to the

[29] https://developers.arcgis.com/javascript/ (01.01.2020)

passive recording of movement trajectories when users are actively using the web app.

To foster awareness and understanding of technical features and issues in the context of mobile phones' hardware and background processings, two minor changes were implemented. First, the user was informed with *red banner text* when web access was interrupted, indicated by missing map updates, thus became aware of the invisible mobile data coverage. Second, a fixed *speed* display in the top right corner gave the user information about the speed in km/h. In cases of poor positional accuracy (> 50 meters) and no speed (speed = 0), a MOVE command was displayed to indicate that the user should start moving. Through position feedback, users learn experientially about positioning on their own smartphones and become aware of the continuous use of the sensors and their variations in measurement quality.

3.3.3.2 Case study 4 with vocational school apprentices

Teachers and students undertaking the vocational training course for agriculture "General education for Agriculture" at Berufs- und Weiterbildungszentrum Obwalden in Giswil volunteered to carry out an in-depth case study for this research. Their work provided essential findings in preparation for the core study. The motivation of this research was twofold: First, the study should return feedback on the design (instruments, procedure, and analysis) with a sample of potential participants that represented a typical class structure and size. The findings should ensure that teachers can plan, prepare, implement, and conduct an LBML unit without technical issues and didactical limitations. Another purpose of this longitudinal study was to ascertain if the apprentices remained motivated to carry out three surveys objectively over a long period, given they received no monetary reward or gift-in-kind. Secondly, the study should, as an experiment, show the learning outcomes of apprentices using OMLETH. The central hypothesis investigated in this experiment that relies on MRQ3 (see Section 1.2), was the following:

> H3.3 A location-based mobile learning tour with OMLETH within a regular classroom teaching session will lead to improved results in examination outcomes

To obtain insight into the cognitive and affective domain of the learning process after the experiment, further investigations were deemed necessary if learners demonstrate higher self-assessment, especially in cognitive ability and if they benefit from and remember the learning content of the location-based mobile learning lesson after three months.

The investigation involved several important steps, such as after the experiment, after the examination, and long-term after several months:

3.3.3.2.1 Methodology

Twenty-five apprentices willingly enrolled in this course, and two teachers voluntarily participated. The students' average age was 20.5 years (SD: 2.8, MIN: 18, MAX: 25). Neither students nor teachers received a monetary reward or a gift-in-kind for their participation. However, for the apprentices who could use OMLETH, the new teaching method was expected to offer a welcome change from everyday teaching. Also, the anonymous survey results, detailing the new method of teaching, were provided to the teachers.

Course objectives

The teaching objective was to enable the apprentices to distinguish and evaluate the most important trees and plant species of the agricultural sector and assess their state of health. The apprentices were taught in the classroom about theories and procedures for the determination of species. The apprentices were expected to reproduce and apply existing knowledge in a familiar environment using the following skills:

- **Subject-based skills** to analyze and identify trees and plant species of the agricultural sector and to assess their state of health.
- **Spatial awareness and map reading skills** for wayfinding and describing the spatial context of the (natural) location of the trees and plants.
- **Soft skills** for working independently in groups of two or three.

The examination tested only subject-based skills. The grade counted for one-third of the semester grade.

The teaching unit lasted five weeks. The first three weeks focused on the acquisition of theories, phenomena related to vegetation in an agricultural context, and the most important features of a collection of tree species. The fourth week was dedicated to learning transfer, where the theory was to be elaborated on through self-study. During this week, 50% of the apprentices of the treatment group participated in the geolearning tour using OMLETH, while those in the control group remained in class. In week 5, the apprentices sat an exam.

Variables

Regarding the variables, the controlled, independent variable was the LBML activity while the dependent variable was the examination grade, which assessed the cognitive learning goals. Some explanatory variables included the self-assessment about the cognitive and affective learning outcome with repeated measures (after the experiment, after the examination, and in the long-term course).

Instruments and performance measure

Several instruments were used in carrying out the evaluation. These included: direct observation of the apprentices during the execution of the experiment; a questionnaire for the experimental group after the treatment; an examination related to the cognitive goals with real grades for both groups; a questionnaire of the overall experiences regarding the learning effectiveness and usability of OMLETH after the exam and after 12 weeks for the experimental group; and a questionnaire on learning effectiveness after the exam and after 12 weeks for the control group. The results were validated and evaluated by the two teachers and discussed in a structured interview at the end of the study.

The questionnaires contained open and closed questions with a five-item Likert scale to measure cognitive, motivational, and affective objectives, as well as technical performance using the following responses:

- Does not fit at all (2)
- Hardly fits (3)
- Fits sufficiently (4)
- Fits well (5)
- Fits perfectly (6)

The students were instructed to compare the numbers following the Likert values to exam grades. The scale was based on the evaluation of student performance by school grades. Since the teacher stated that grade 1 is excluded if there was any performance to measure, and the lowest performances are assessed as grade 2, grade 2 was also given the lowest rating in the self-evaluation. Grade 4 represents a moderately good performance and is therefore compared to the response type "Fits sufficiently." Grade 6 represents a perfect performance.

Procedure

Figure 21 depicts the procedure of the experimental study, which was three-months long.

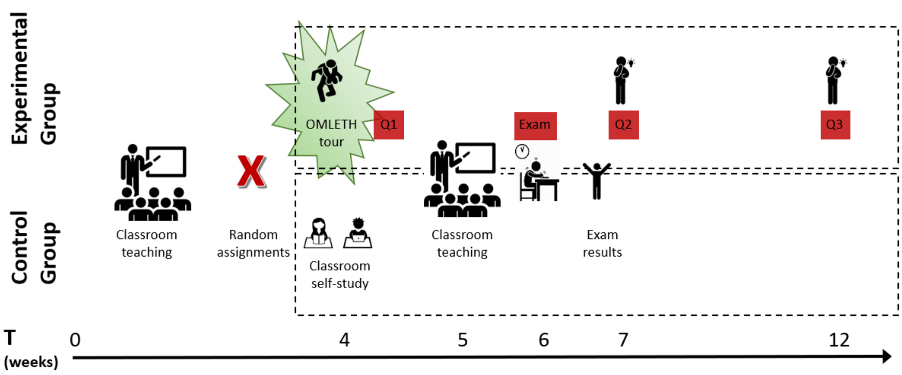


Figure 21 Procedure of the preliminary study.

Weeks 0–4: Classroom teaching and teacher preparation

During this period, the two teachers were instructed on how to use and create an LBML module with OMLETH. They then created an LBML tour as a treatment for the experimental group. The apprentices were then randomly divided into the experimental group and the control group based on the previous two-year examination grades, ensuring two cognitively equally strong groups.

Week 4: Treatment and questionnaire (Q1)

While the experimental group conducted the LBML activity around the school environment, the control group remained in the classroom and worked independently through the previous week's teaching material.

When the experimental group finished the LBML lesson, they took the survey Q1 shown in Appendix I to evaluate their learning progress and to review the usability of OMLETH. In week 5, a class debriefing with sharing experiences was planned and the option using the OMLETH-Viewer.

Week 6: Exam

At the end of the teaching unit, both groups sat the same examination in the classroom, which was managed by one of the teachers.

Week 7: Questionnaire (Q2)

A few days after the grade results were received, both groups should complete the survey Q2 (see Appendix I). The survey was in two parts. The first part targeted the experimental group. They were required to review the LBML lesson (which is described as a tour in the survey) and respond to questions about the LBML as a learning activity. The second part was for both groups to assess their current state of understanding, motivation, and attitude. After taking the survey Q2, the apprentices received the examination results.

Week 12: Questionnaire (Q3)

Three months after the questionnaire was complete, both groups responded to survey Q3 (see Appendix I) The survey was again in two parts. Both groups were asked to indicate their current state of understanding, motivation, and attitude while the treatment group had to re-review the LBML lesson and the examination.

3.3.3.2.2 Results and discussion

This section describes the results of the procedure, the teacher's feedback on OMLETH, the results of the examinations and the apprentices' surveys, and the final enhancement requests for OMLETH.

Study introduction

The study was executed by two teachers who were teaching a general education course on the topic of vegetation in an agricultural context. The goal was the development of an OMLETH LBML activity to merge vegetation theories with teaching practice. They got introduced by a test module around their school with a WhatsApp chat, multimedia content, and embedded and linked content from external web services. Then, together with the two teachers, details of the study schedule were worked out in order to make the study as realistic as possible. Finally, the remaining concerns were clarified in order to launch the study.

Module creation

The teachers created the LBML lesson together for over three weeks. The design encompassed 19 learning stations, with a specified sequence in two possible directions. Thirteen of the 19 stations contained survey assessments, where the apprentices had to describe the trees by text or characterize them through multiple-choice questions. The findings were to be directly reported in the surveys. An exchange with the teacher was not considered, thus explaining why no extra messaging app was embedded.

Heavy workload to prepare the module

Both teachers reported that they usually need two hours to prepare a new regular classroom lesson. For the LBML activity, the teachers (Teacher A and Teacher B) spent twenty-one hours in total preparing the module, excluding the introductory meeting. The main work was to search for good examples close to the school building which was conducted by both teachers.

The digital part of the lesson was completed by Teacher A. The work steps were as follows:

Step	Description	Workload in hours
1	An on-site exploration to test reachability, seeking, and mapping of new trees. Testing the positioning and web access at specific places. Storing remarks and decisions with handwritten notes, and determining the virtual route based on the study of the OMLETH base maps (Teacher A and B)	10
2	The creation of the learning stations' perimeter in OMLETH (Teacher A)	2
3	The creation and testing of the multiple-choice questions for an online survey (Teacher A and Teacher B)	6
4	Linking the online surveys to OMLETH's learning stations (Teacher A)	3

The design did not consider the formal exchange between apprentices and teachers. This was because the primary goal was that the apprentices could solve the tasks independently without teacher assistance. An existing class chat (WhatsApp) was embedded for emergency purposes. For the control group, the opportunity was offered to recapitulate the learning content with existing materials and literature from the library.

Module event

Observation

The tour took place in the vicinity and familiar surroundings of the school. The participation of the module event and the classroom session was mandatory. However, due to illness, only 12 of 13 apprentices executed the tour, and 11 of 12 apprentices did self-study in the classroom. In the beginning, in six groups of two, the tour members were distributed to different stations. The weather, at that point, was wet, and the temperature was 15 degrees Celsius. However, upon the apprentices returned to school, the weather became pleasant and dry. Some of the apprentices did not complete all 19 learning stations, were not excessively motivated, and verbally reported that finding the trees was difficult because the device position in OMLETH-Player did not overlap with the learning station's perimeter.

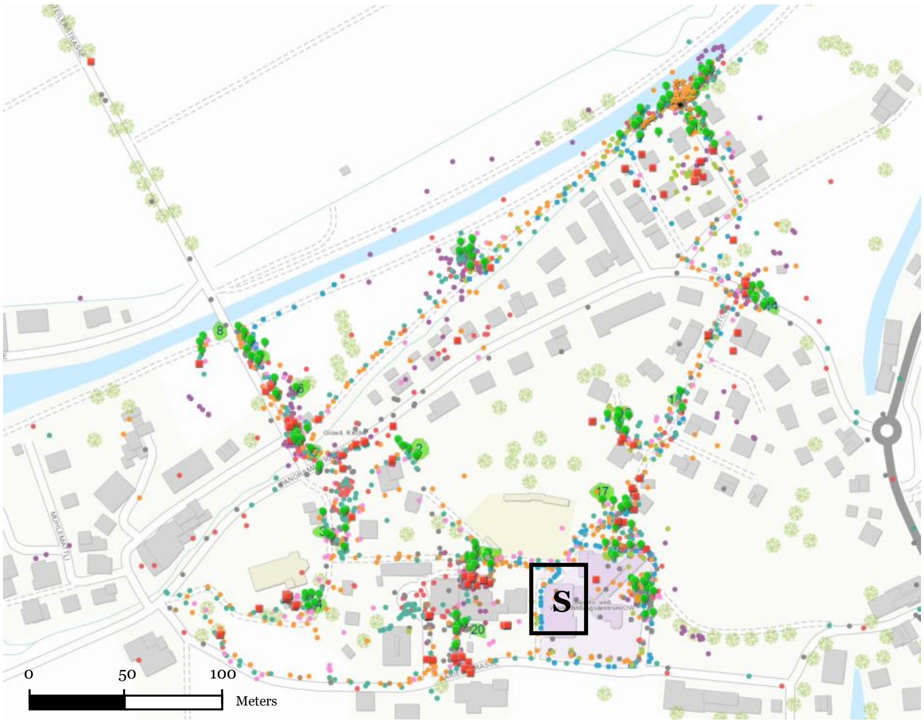


Figure 22 Apprentices executing a field study in Giswil are differentiated by colors and visualized as point clouds on a static 2D map, including the start (black rectangle). The larger light green icons are the successful station requests, while the larger red icons are the failed station requests. (Software: © OMLETH; base map: © Esri)

Figure 22 depicts a representation of the LBML area, including the small learning stations, which are overlapped by the point clouds of 12 apprentices and the learning station requests in larger green icons (successful requests) and larger red icons (failed requests). At first glance, the map shows many light green icons, which means that the apprentices successfully executed the learning tasks when requested. However, there are also red icons, mainly from the same three apprentices, which indicate that they needed several attempts to access the learning task. The pattern of the point clouds reveals that several routes had been taken to reach the learning stations. A perplexing case occurred with the grey-colored group that crossed the river heading northwest to the upper left corner of the map. The map shows large gaps between two adjacent points recorded with a rate of eight seconds, which indicates high velocity. The two involved apprentices reported that they took the liberty as they read and acted on one's own authority without permission from the teachers using a car to reach the stations. However, the map analysis and speed values revealed this action.

Tour survey

Back in the classroom, the experimental group completed a brief survey. Figure 23 (left) shows the apprentices' self-assessment of their progress in understanding, motivation, and attitude. The twelve apprentices reported their understanding with an overall average score of

3.6 (SD=1.2, MIN=2, MAX=5), motivation with an overall average score of 3.3 (SD=0.9, MIN=2, MAX=5), and attitude toward the topic with 3.4 (SD=1.1, MIN=2, MAX=6) as overall average score.

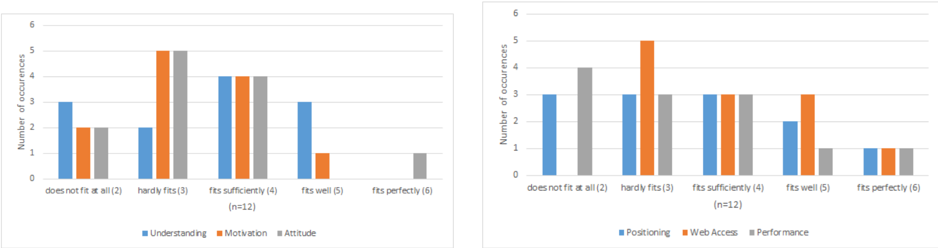


Figure 23 Tour feedback of Giswil's apprentices: (left) Self-assessment of the progress in understanding, motivation, and attitude of the experimental group after the tour; and, (right) technical feedback about positioning, web access, and performance of the OMLETH-Player.

Figure 23 (left) depicts the technical feedback. The negative feedback of the self-assessment shows some correlation with the feedback on the positioning with an overall average score of 3.6 (SD=1.3, MIN=2, MAX=6) and performance of the OMLETH-Player with an overall average score of 3.3 (SD=1.3, MIN=2, MAX=6). Web access was reported as sufficient, with an overall average score of 4.0 (SD=1.0, MIN=3, MAX=6).

The feedback on LBML as a teaching approach showed that 9 out of 12 apprentices considered it to be as valuable as classroom lessons. One student saw little sense in using technology when the same tasks could be done with paper and pencil. The question of familiarity with their mobile phones in schools showed that the apprentices had minimal experience with using mobile phones in school as an educational tool. One apprentice used a borrowed smartphone for the first time. The general impression seemed to be that they did not like mobile phones, particularly in educational contexts.

The open question item further revealed that the linked web forms were challenging to use because the teacher placed the web forms in an "iFrame" (size of half a screen width and length), instead of linking the item to open in separate tabs to benefit from the full size of the phone's display. This issue meant that the apprentices tediously had to scroll in the dimension-fixed iFrames of OMLETH's popup.

In the week between the OMLETH experiment and the examination, the two teachers conducted a short tour debriefing in the classroom to discuss the results by means of the OMLETH-2D-Viewer showing the content of Figure 22 and to clarify open questions. This lesson was not part of direct observation.

Examination

The examination took place with all 12 apprentices of the tour, who undertook the tour, but only 7 of the 11 apprentices of the control group.

Although exam grades often correspond to the results of transformed examination scores, and thus correctly compare to an ordinal scale, teachers routinely use them as an interval scale to calculate semester grades. Therefore, the grades were treated as interval scales in this study as well.

An independent samples t-test indicated that there was no significant effect, $t(17) = 0.64$, $p = .265$, despite the users of the treatment group using OMLETH ($M = 5.76$, $SD = 0.6$, MIN=3.9, MAX=6) attaining higher scores than control group members ($M = 5.6$, $SD = 0.4$, MIN=5.3, MAX=6). Hypothesis **H3.3** was statistically rejected. However, the small sample size of both groups resulted in low statistical power and reduced the chance of detecting a statistically significant effect.

Exam survey

A few days after the class received the exam results, both groups undertook the exam survey. The experimental group had to think about the outdoor experiment again. While 10 of 12 group members enjoyed the LBML unit, the statement "I enjoyed learning on my mobile phone" only fitted well with 6 of 12 group members.

Figure 24 depicts the graph of the experimental group (left) and the control group (right). It represents the apprentices' state of self-assessment in terms of understanding and motivation, and how they assessed their attitude towards vegetation in an agricultural context.

- The experimental group reported their understanding with an overall average score of 4.7 (SD=0.8, MIN=3, MAX=6), while the control group reported an overall average score of 4.9 (SD=0.7, MIN=4, MAX=5).
- The experimental group reported their motivation with an overall average score of 4.1 (SD=1.1, MIN=2, MAX=5), while the control group reported an overall average score of 4.6 (SD=0.8, MIN=4, MAX=6).
- The experimental group reported their attitude with an overall average score of 4.0 (SD=0.9, MIN=2, MAX=5), while the control group reported an overall average score of 4.4 (SD=0.5, MIN=4, MAX=5).

Both groups assessed their understanding, motivation, and attitude as sufficient after the exam. However, the distribution of the three learning objectives in the experimental group showed higher heterogeneity than that of the control group.

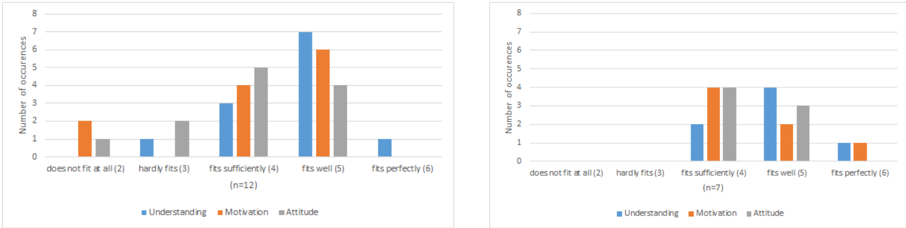


Figure 24 Examination feedback of Giswil's apprentices: Self-assessment of progress in understanding, motivation, and attitude after the exam: (left) the experimental group; and, (right) the control group.

Long-term survey

The apprentices conducted the last survey six weeks after the exam. Figure 25 depicts the results of their understanding, motivation, and attitude, including their interest in the topic of trees and plant species of the agricultural sector before the teaching unit started. It shows significant variance between the groups in their interest in trees and plant species. As shown, the experimental group had a lower overall average score of 3.5 (SD=1.3, MIN=2, MAX=6) than the control group, which had an overall average score of 4.0 (SD=1.3, MIN=2, MAX=6). The self-assessment of both groups showed similar trends to the interest in the topic before the teaching unit

- The experimental group reported three months after the examination of their understanding with an overall average score of 3.7 (SD=1.4, MIN=2, MAX=6), while the control group reported an overall average score of 4.0 (SD=1.2, MIN=2, MAX=5).
- The experimental group reported their motivation with an overall average score of 3.5 (SD=1.0, MIN=2, MAX=5), while the control group reported an overall average score of 3.6 (SD=1.3, MIN=2, MAX=5).
- The experimental group reported their attitude with an overall average score of 3.0 (SD=1.1, MIN=2, MAX=5), while the control group reported an overall average score of 4.4 (SD=1.0, NIN=3, MAX=6).

The results show that the most significant difference between the groups was reported in attitude toward the learning subject. This is shown most prominently in Figure 25 (left), where six out of twelve apprentices reported no interest in the topic at all. Possible reasons for this aversion could be because apprentices in vocational schools have different occupations, and those who do not pursue a profession close to agriculture have no incentive to be interested in it. The massive decrease compared to the examination questionnaire could be influenced by the fact that the students got assessed a few days after they received the examination results. Due to the generally very good examination results, the results could also bias the self-assessment scores of the examination questionnaire. This is shown in understanding with a score decline of 1.0 at the experimental group and 0.9 at the control group, in motivation with a score decline of 0.6 at the experimental group and 1.0 at the control group, and attitude with a score decline of 1.0 at the experimental group. Only the control group did not show a difference in the average score of attitude.

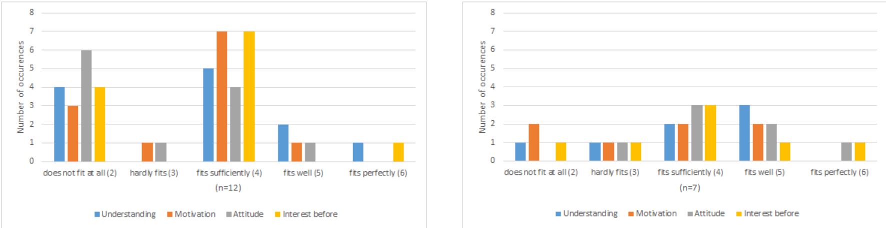


Figure 25 Long-term observation feedback of Giswil's apprentices: Self-assessment of the current understanding, motivation, and attitude and of interest before the course; (left) the experimental group; and, (right) the control group.

When comparing the results between the examination survey and long-term survey, it is evident that both groups had a negative trend that matches the *Forgetting Curve of Ebbinghaus* (Murre & Dros, 2015). However, 50% of the experimental group believed that they still could concretely explain the content of some of the learning station's topics and would remember the tour experience if they encountered the learning content in real life.

The concluding questions concerned the summative assessment of the teaching sequence and how they prepare. One question asked about the likelihood of repeating the existing OMLETH learning module. In the current study, none of the apprentices repeated the existing OMLETH learning module. If the final examination were to be designed as an LBML activity, then 50% of the apprentices stated they would repeat the OMLETH learning module, to exercise the situated tasks.

Results review and discussion with the teachers

After the study, the two teachers validated and discussed the results of the questionnaire in a structured interview. They started by reviewing the preparation process. They emphasized that their primary goal in using the LBML approach was to implement an activity in which class theories are applied independently. Therefore, the teachers were not conducting an active interaction between teachers and apprentices through online conversations. The teachers noted that the preparation of the learning tasks was time-consuming and, with the total of external online surveys and link management, complex in terms of organization. They reported that the biggest shortcoming of the OMLETH Creator was its inability to control digital work directly on the desktop computer. They suggested a viewer that would match the size, shape, appearance, and behavior of the web implementations.

The teachers observed a relatively high commitment on the part of the apprentices to achieve good results in their examinations. In retrospect, the examination was too simple, which was reflected in the high grades. The two teachers interpreted the rather negative self-assessment of the experimental group as too poorly introduced apprentices for the application of the LBML as a new learning approach. The apprentices were not used to perform outdoor learning tasks without the presence of the teachers on site.

Concerning the results of the examination survey, the two teachers confirmed the bias caused by the examination result in the self-assessment of the examination questionnaire. They assume that the long-term results would rather reflect the actual attitude. The large increase of the understanding of the experimental group may have been caused by one or more of the following three factors: debriefing one week after the experiment; serious preparation for the examination; or, possible bias amongst the apprentices after receiving exam results a few days before. The teachers further concluded that the overarching learning objectives and the practical relevance for everyday work, such as self-directed, independent learning, and self-reliance, need to be reinforced to achieve better results in the learners' own self.

The teachers believe there were possibly two reasons why no apprentice repeated the LBML activity. First, as the final apprenticeship examination was held two months before the study, the apprentices suffered a loss of extrinsic motivation towards any voluntary school activity. Second, as the exam format was in the classroom, accustomed and optimized strategies for classroom test preparation prevented apprentices from being motivated to repeat the LBML activity.

When discussing the procedure and instruments, the teachers pointed out the number of questions in the questionnaires and the critical length of time to complete them. The teachers acknowledged that although the questions were comprehensible, the number of items was at the upper limit, as the apprentices were not used to such structured self-assessment, and its meaning had not been discussed in-depth. The apprentices' drop-out rate was high, at 6 out of 25. Reasons were the absence during the exam due to illness of three apprentices, two apprentices were not willing to participate in the questionnaires after the exam, and one withdrew from the apprenticeship within six weeks after the exam.

3.3.3.2.3 Technical design and study design findings

The case study revealed the following findings regarding the technical design of OMLETH 3.0:

F3.4.1 Sharing preparation and planning was carried out successfully with the OMLETH-Creator.

F3.4.2 The confusion between the learning station item-link and iFrame confirmed that teachers need to be technically well-instructed before they start creating content in the OMLETH system. If necessary, teachers must be accompanied during the preparation.

F3.4.3 Testing directly on the desktop computer would save the effort of testing outdoors. The test tool would have to simulate a view and behavior as identical as possible to that of the mobile phone.

The case study revealed the following findings regarding the study design:

F3.4.4 The questionnaires were provided with comprehensible questions and resulted in valid answers. The optional comments were rarely completed, thus additional items to increase validity may have led to the loss of participants (fatigue and motivation). It was, therefore, judged not to be an option.

F3.4.5 The self-evaluation on cognitive and affective assessments (after the release of the grades) was deemed unsuitable for an objective self-evaluation. The outcome indicated that the examination questionnaire should have been completed before the personal disclosure of the results to reduce the bias resulting from the examination grades.

F3.4.6 The combination of a cross-sectional study for examination evaluation, and a longitudinal design for self-evaluation, showed that the sample decreased over time due to several missing participants. Thorough guidance and close supervision of the teachers over several weeks is required.

3.3.3.2.4 Summary and conclusion

This study with a sample size of 19 apprentices found a statistically nonsignificant increase in examination outcome for learners who participated in the LBML activity. The case study revealed that the statistical power was far too low, number and clarity of the questions were reported as comprehensible, the procedure needed minor changes such as the timing of the examination questionnaire, and the quality of answers showed good validity with respect to the known bias, according to the two teachers. To prevent the iFrame issue, the teachers proposed for future work a tool that can test the ready solution of the OMLETH design in the office using a desktop computer.

3.4 Discussion and conclusion

This chapter has detailed the research-based design of an LBML technology to allow geolearning with mobile phones or tablets, GIS, and GPS. OMLETH, an LBML GIS that is directly accessible via web clients, shows low technical barriers and consists of no subject-specific design limitations. It is easily connectible to existing content and services, and can be built in modules to enable long-term maintainability and adaptability. Using the RBD approach, different features and designs were tested, adjusted, and retested over several years in a real educational context. Through this research and technology, lecturers and teachers were able to prepare, execute, and review LBML activities. As a result, several hundred students used the OMLETH-Player within the presented case studies and many other explorative studies in schools and leisure activities (Christian Sailer, Kiefer, & Raubal, 2018).

The final evaluated prototype was completed with minor usability adjustments and an emulator in the map view of the OMLETH-Creator (**F3.4.3**). Figure 26 shows the map view of the OMLETH-Creator, with the OMLETH-Player as an HTML pop-up and an emulated mobile device in front of the map view. The emulator allows simultaneous testing of the implementation while the user manipulates the learning content. The emulator device size can be used as a small smartphone in a portrait format of 300 x 500 pixels or as a tablet in a landscape format of 500 x 700 pixels. The device also allows custom configurations. The two teachers in the last case study successfully tested the emulator (see Section 3.3.3.2).

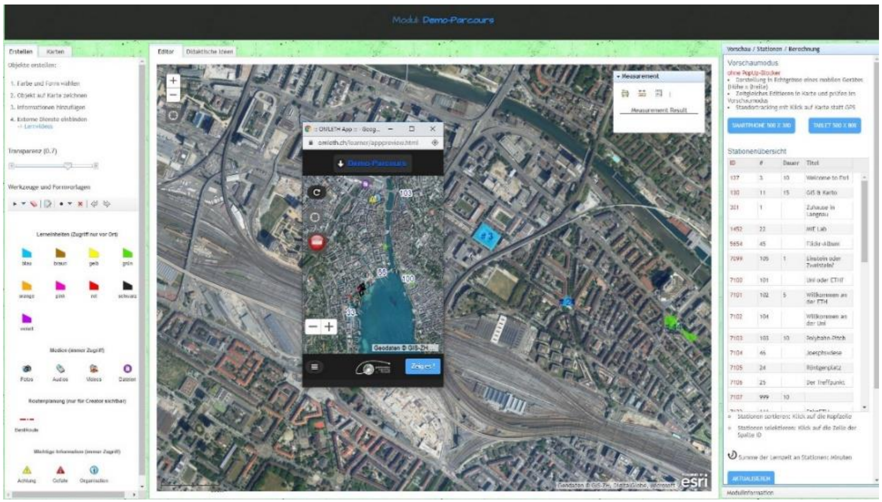


Figure 26 OMLETH-Creator map GUI including the emulator as pop-up

Moreover, to be able to use the user data and learning content for further evaluations in other products, the OMLETH-Viewer was extended with a data extract feature. This feature allowed teachers and learners to export their user data and learning content represented as web map services to exchangeable file formats in different options. Point feature data like the movement trajectories can be exported to file formats such as CSV, KML, or shapefile, including the x and y coordinates, and polygon feature data like the learning content can be exported to a KML or a shapefile. With these formats, it is possible to use the files in other GIS applications, such as Google Maps or OpenStreetMap, that support standardized data formats, or statistical applications.

3.4.1 Key features of LBML GIS

Research question 3.1 concerned the extraction of the key features of this study's LBML GIS. This included an examination of the entire teaching and learning process of the LBML unit, including planning and preparation, and execution and analysis. The OMLETH user interface utilizes geoinformation technologies, such as geoprocessing services and map services of different cloud servers, to make the learning content geographically accessible in a GPS-enabled web browser.

Table 4 summarizes the key features of the OMLETH-Creator, OMLETH-Player, and OMLETH-Viewer that were extracted in the first, second, and third design. With the OMLETH-Creator, lecturers organize their content in separate modules of a course, whereas in the map view, the content is created as learning stations. The technological capabilities of OMLETH, such as the linking of external systems and services, allow creators unlimited design choices with multimedia. The route planner assists the allocation of the learning stations, and the emulator represents the module in a mobile device-sized pop-up to test the implementation within the creation process. Modules can be co-authored or shared as templates. Learners use the OMLETH-Player to access the content by requesting the learning content as they are entered within the learning station. The OMLETH-Player's display provides information in real-time. This enhances the understanding of positioning technology, position accuracy, and speed. To analyze the learners' activity in real-time, the OMLETH-Player records the movement position data and the learning station request data and visualizes the trajectories in the OMLETH-Viewer as 2D and 3D representations. An export data feature allows analyzing the personal user data and learning content in other applications.

	Solution 1	Solution 2	Solution 3
OMLETH-Creator for teachers	• Course view • Module view • Map view of the learning stations	• Route planner • Reuse of resources • 2D-Viewer of the positions	• Sharing of resources • Co-creation of resources • (Emulator)
OMLETH-Player for learners	• Map view of the learning stations • Position recording	• Position tracking • Position accuracy display • Learning station request recording	• Speed display • Web access display
OMLETH-Viewer for teachers and learners			• 2D-Viewer of the positions and learning station requests • 3D-Viewer of the positions • Export data
Further capabilities	• External services by URLs	• External resources by iFrame • Video tutorials	

Table 4 Overview of the key features of OMLETH's clients.

Teaching an LBML GIS

Research question 3.2 concerned how teachers conduct LBML teaching with a GIS, including the planning and preparation, the execution of the LBML unit, and the debriefing activity. The preparation of the four case studies showed that LBML teaching involves a much higher workload than classroom teaching. It generally includes on-site inspection and brainstorming, and the study of online maps to spatialize the learning content. Although OMLETH Creator allowed the use of tablets, none of the creators of the case studies prepared the polygons and digital content directly in the field. The creators preferred to make notes on paper, which formed the basis for the creation of the learning content in OMLETH and the external services. The implementation procedure usually alternated between the design of the learning stations and content and the on-site testing. Together, the requirements for conducting LBML teaching were highly time-consuming for the teacher.

Given that the lecturer in architecture was not familiar with digital teaching, the workload of the reference example in the first case study was 17 hours. By comparison, in the follow-up study, the workload was reduced by an average of 8 hours, although the lecturer varied the didactical concept for each module. The workload required by the teachers to build an LBML unit in the preliminary study was 21 hours. This included several co-teaching steps in the planning and preparation process.

Regarding the teachers' participation during the LBML lessons, the lecturer of the architecture students was usually on-site, at least at the time of the seminar lecture to introduce or debrief the topic. The teachers in the other two case studies were not present during the field visits with the purpose of fostering the soft skills of self-management and independent problem-solving. However, minimal teacher supervision also allowed for freedom and fun amongst some students, as evident by the two students who used their car in case study 4.

The classroom debriefings were significant to clarify the remaining issues and to apply the examples experienced to overarching theories and learning objectives. Analysis of the OMLETH-Viewer determined that the 2D-viewer is a valuable reference tool for reviewing the activities in groups and for allowing in-depth analysis. The 2D-viewer is also helpful in differentiating discussion about places visited, through the information provided by the trajectories. For large numbers of students, open explorations and specific pattern analytics such as students' relatedness, the use of the 3D-viewer is inevitable.

3.4.3 Conclusion

OMLETH is an LBML system with advanced GIS functionality that offers features that go beyond the location-based mobile part of an LBML activity. Remote access to learners' current positions from anywhere as they navigate to mainly known destinations, enables teachers to interact in real-time to give learners advice, provide adaptive further instructions, and check their understanding when needed. Issues, such as positioning, wayfinding, or safety, can also be identified and addressed. Furthermore, the learner's movement trajectories and learning stations visualized in the 2D and 3D map context enable precise spatio-temporal context analysis of the learning process and help to remember about special learning experiences. This allows teachers and learners to conduct in-depth debriefings of the LBML activities in class or individually and facilitates the linking of new learning contents in the follow-up lessons to events of the LBML activity and thus also to at least virtually situate future taught learning concepts. Analogous to the geographic inquiry process in mobile GIS (see Figure 8), the data provides the opportunity to address new didactical research questions in the domain of geolearning and GEES disciplines. With regard to project-based learning, future work in the field of learning science can be seen in the interdisciplinary work of mobile GIS and LBML. Thus, the contribution of GIS technologies extends the LBML activity from outdoor pedagogy to project-based learning approaches and the field of learning analytics from LMS-known graph-based to map-based visualizations. This technical and didactic extension, however, leads to a higher workload for teaching, and therefore requires first and foremost, a considerable conviction of the learning strategy. Teaching LBML requires additional skills compared to classroom teachings, such as spatial cognition skills, and information and communications technology (ICT) skills, and the will to work creatively and intensively to produce high-quality designs. Regarding the statistical outcome for LBML learners on cognitive learning achievement, there is as yet no scientific evidence that the introduction of OMLETH also helps learners. Therefore, further research with a large-scale study is needed to analyze the learning process and learning success systematically.

4 Evaluation of location-based mobile learning

The first part of this dissertation consisted of a qualitative study over several years, which enabled the development of the location-based mobile learning platform OMLETH. Consisting of four case studies, the study explored usability, satisfaction, and the learning process, along with students' and teachers' reflections (see Chapter 3). Students from different school levels were assigned formal and informal activities. On-site observations, content analysis of open-ended surveys, reflective journals, and direct interviews provided a rich view of the teaching and learning experience. Nevertheless, the study returned, expect case study 4 (see Section 3.3.3.2.2), no quantitative evidence about summative learning outcomes of location-based mobile learning with OMLETH, and no systematic results about the ability to recall learning content or situational experiences in the long-term.

Researchers have published in the field of LBML since the emergence of mobile technologies. LBML studies have evaluated usability (will it work?), effectiveness (is it enhancing learning?), and satisfaction (is it liked?) (Sharples, 2009). Abe et al. (2005) and Ruchter et al. (2010) reported a general increase in interest in nature despite usability issues where people voluntarily participated with a positive bias towards using mobile devices. Uzunboylu et al. (2009) found improvements in attitudes and awareness of environmental concern problems among students who voluntarily participated in a non-regular curriculum, six-week study. A significant increase in knowledge progress was reported for primary school students in the study of Huang et al. (2010) and Looi et al. (2011), and secondary school students in the study of Huizenga et al. (2009). No effects regarding knowledge progress were evident in the study of Ruchter et al. (2010), which, based on a study of 185 students from a primary school, investigated the impact of a mobile guide system on different parameters of environmental literacy in comparison to traditional instruments of environmental education.

An evident characteristic of these studies was that learning with mobile devices in schools was not a familiar concept or approach amongst the participating students. Mobile devices were rarely found in the regular curriculum, and participants were always satisfied despite the usability problems and regardless of the learning approach (Sharples, 2009). Mostly, empirical studies were conducted in isolated school projects without the influence of the daily challenges and future relevance of the learning outcome. Therefore, there is a lack of insight into the effect of LBML when mobile devices have leveraged teaching and learning of the regular curriculum, and when the effectiveness is measured against real-life situations. Furthermore, Uzunboylu et al. (2009) suggested that future studies should include larger samples than just the comparison of two classes, real curriculum situations, and extend for longer durations than six weeks. Thus, to make the utmost use of the mobile phones and to obtain scientific evidence about the effect of location-based mobile learning, schools and teachers that fitted the affordances of LBML were sought in the following way:

- The curriculum should promote not only **subject-based learning goals**, such as course knowledge or course skills, but learning goals related to **soft skills**, such as communication, teamwork, responsibility, positive attitudes, and professionalism, using mobile technology as scientific instruments.
- Field-based education is a known teaching scenario and teachers are aware of implementation techniques that take advantage of its pedagogical affordances such as **spatial thinking skills**.
- Teachers should have experience in using **digital media** (ICT skills) in general, as well as science-based technologies such as digital **maps, GIS, GPS,** and other sensing instruments in particular.

Geography in Swiss secondary schools

Based on these criteria, teachers and students within Geography were identified as the study group of interest. Further, students needed to be in secondary schools leading to Matura graduation. Schools with Matura graduation offer a broad and comprehensive academic basis and prepare students for direct entry into university.[30] The specific requirements for a Matura graduation vary slightly among Swiss cantons, but in the case of Geography, the grades of the last school year at the end of the 12th or 13th grade are included in the marks of the Matura certificate. The recognition of Matura schools is regulated by the Swiss Federal Council and the Swiss Conference of Cantonal Ministers of Education (EDK). The EDK developed the subject-specific learning objectives in the core curricula (CC) under the premise that Matura schools provide the foundation of knowledge, skills, and attitudes that enable students to expand their knowledge in any field. The CC from 1994[31] recommend provisional goals for Geography in the following three levels as guidelines:

- **Knowledge**: Students should be familiar with fundamental subject-specific terms and have basic topographical understanding to interpret, classify, and locate current events geographically. They should be able to identify landscape elements and the factors shaping landscape change and know the basic features of the geology of Switzerland.
- **Skills**: Students learn to experience a landscape in its entirety consciously and to analyze it with the help of geographical methods and skills. Students should be able to read maps and to orient themselves in the field. They should be able to interpret geographical presentation methods, thematic maps, diagrams, statistics, models, pictures, and texts and present and share the results of geographical inquiries in an understandable way. They should be able to identify geographical factors and understand processes using models and case studies. They should be able to observe, recognize, interpret, and assess landscape elements, their structures, and their interactions.
- **Attitudes**: Students should experience interaction with other people, cultures, and landscapes as a form of enrichment and understand their environment better by making comparisons. They should rethink their attitudes through personal experiences and lessons learned to become aware of problems that arise and establish ways to solve them. They should question spatially relevant activities and act accordingly in a responsible manner.

[30] https://bildungssystem.educa.ch/de/gymnasiale-maturitaetsschule-gymnasium (01.01.2020)

[31] Rahmenlehrplan für die Maturitätsschulen, 9.6.1994, http://www.edk.ch/dyn/11661.php (01.01.2020)

Due to this three-level separation, this study focuses on how students perceive the LBML activity regarding cognitive and affective outcomes. In addition to the provisional subject-related goals, the CC also contains the general objectives of Matura education, which aim to outline the objectives and common aspects of the individual subjects of the Matura schools within an overall pedagogical framework. These pedagogical fundamentals include social, epistemological, communicative, personal development, and methodological skills, which will indirectly affect the study results as well.

The remainder of this chapter is structured as follows. Section 4.1 introduces the methodology with the central hypothesis and four chapter-specific research questions that relate to the dissertation's main research questions. This section also describes the participants, the variables and instruments, and the procedure and analysis. Section 4.2 presents the results, along with a summary of the specific findings. Section 4.3 offers a discussion of the results and presents concluding comments from the study.

4.1 Methodology

4.1.1 Research questions and hypothesis

The goal of this study was to determine the impact of a location-based mobile learning lesson within a regular teaching sequence. The study sought to examine learning outcomes through a regular examination, students' self-assessments, and long-term memory effects. A systematic analysis of the planning, preparation, and implementation of the LBML was necessary to determine the extent to which the teaching strategies for implementing a real LBML scenario differ from those in other learning environments such as classrooms or e-learning courses. Specifically, the study was designed to address the following research questions[32]:

RQ4.1: How do teachers plan and prepare when developing an LBML activity?

RQ4.2: How well does movement analytics explain how students perceive usability regarding positioning and web access?

After the experiment, the students were given a real exam to test their learning progress. The grade of this exam was part of the semester's final grade. This led to the following hypothesis:

[32] The leading «4» indicates the chapter and is introduced to differentiate the chapter-specific research questions from the dissertation's overall research question.

H4.3: A location-based mobile learning lesson within a regular classroom teaching session will lead to improved results in examination outcomes.

To obtain insight into the cognitive and affective domain of learning process after the experiment, further investigations were deemed necessary. The following research questions address several important steps, such as after the experiment, after the examination, and long-term after several months:

RQ4.4: Do learners who attended a location-based mobile learning lesson within a regular teaching unit demonstrate higher self-assessment, especially in cognitive ability?

RQ4.5: Do learners benefit from and remember the learning content of the location-based mobile learning lesson after three months?

4.1.2 Participants

To achieve a power calculation of the Two-Sample t-Test (unequal sample sizes and unequal variances), the pwr.t2n.test package in R (R Core Team, 2017; Sakai, 2018) was used. The analysis revealed that a sample size of 120 participants was sufficient to achieve a power of 0.8 for an alpha of 0.05 and a large Cohen's effect size d (d=0.5). To account for the clustering effects (school classes, teachers, and schools) and potential dropouts, the plan was to recruit 150 students. A call for participation was sent to more than 150 German-speaking Geography teachers from 80 different Matura schools, where Geography is taught several hours per week over several semesters. Participants were not offered a monetary reward for their time. Instead, they were informed that they would gain experience with a new teaching approach, and teachers were to be provided with anonymous survey results.

Six teachers at four Matura schools from Beromünster, Zürich, Olten, and Aarau agreed to participate in the experiment. Table 5 depicts an overview of the six experiments using six different classes and 128 students. For the students, participation was compulsory. However, 21 students did not complete the study due to illness or lack of motivation. Consequently, the final participant data was from 107 students (age range 16–18, 42 females / 65 males) and six teachers (one female and five males). All responses remained anonymous throughout the research. The experimental group (EG) contained 56 students, the control group (CG) 51 students.

#	Classes by school	Involved teachers	Pupil's average age	Registered students	Students completed	Dropout rate
1	Beromünster	1	16.5	18	17 (9/8)	5.5%
2	Zürich 1	2	17.3	16	15 (8/7))	6.2%
3	Zürich 2		17.2	19	11 (7/4)	42.2%
4	Olten 1	1	16.0	16	11 (7/4)	31.2%
5	Olten 2		16.1	21	18 (8/10)	14.3%
6	Aarau	2	17.1	38	35 (17/18)	7.9%

Table 5 Metadata for the six classes from four schools.

Beromünster

Kantonsschule Beromünster[33] conducted one experiment with one class of 17 students. The experimental group contained nine students (six females and three males) and the control group eight students (six females and two males). They had an average age of 16.5 years (SD: 0.3, MIN: 16, MAX: 17).

Zürich 1 & 2

Freies Gymnasium Zürich[34] (FGZ) conducted two experiments using the OMLETH module. Fifteen students completed the first experiment, with eight students (two females and six males) in the experimental group and seven students (two females and five males) in the control group. The students had an average age of 17.3 years (SD: 0.5, MIN: 17, MAX: 18). Eleven students completed the second experiment, with seven students (three females and four males) in the experimental group and four students (three females and one male) in the control group. The students had an average age of 17.2 years (SD: 0.4, MIN: 17, MAX: 18).

Olten 1 & 2

Kantonschule Olten[35] (KSO) conducted two experiments with two classes using the OMLETH module. Eleven students from class 1 completed the experiment, with seven students (five females and two males) in the experimental group and four students (one female and three males) in the control group. The students were all 16 years old (SD: 0, MIN: 16, MAX: 16). Eighteen students from class 2 completed the experiment, with eight students (three females and five males) in the experimental group and ten students (four females and six males) in the control group. The students had an average age of 16.1 years (SD: 0.3, MIN: 16, MAX: 17).

Aarau

Alte Kantonsschule Aarau[36] (AK) conducted one experiment with one class of 35 students. This class was initially separated into two classes but

[33] https://ksberomuenster.lu.ch/ (01.01.2020)
[34] https://www.fgz.ch/about-fgz/portrait/about-us/?L=1 (01.01.2020)
[35] http://kantiolten.so.ch/ (01.01.2020)
[36] https://altekanti.ch/ (01.01.2020)

came together for two years as one class with two teachers for Geography lessons. Seventeen students (three females and fourteen males) completed the study in the experimental group, and eighteen students (five females and thirteen males) completed it in the control group. The students had an average age of 17.1 years (SD: 0.3, MIN: 17, MAX: 18).

4.1.3 Study design

This experiment included a mixed design in which the experimental group got one treatment as LBML activity. A between-subjects design was employed for the comparison of the experimental group and a control group on a summative assessment and two repeated measures of self-assessments after the summative assessment. Within-subjects designs were used to obtain information about the emergence of learning progress for the experimental group after the treatment involving three repeated measures and for the control group after the examination using two repeated measures.

The population structure of the educational system is defined by a hierarchical organization (i.e., students are nested in classrooms, classrooms are nested in schools). Therefore, the treatment effect can be distorted and systematically influenced by individual groups (clusters) such as classes, teachers, and schools. Several studies reported measurable differences between schools and teachers in terms of their impact on student learning indicators (Sanders & Horn, 1994). The experimental design of this study, therefore, is described as a clustered design of secondary school students with a nested structure of individuals (by class, teacher, and school).

4.1.4 Preliminary study

A preliminary study was conducted in the previous iteration of the case study series in Chapter 3 (see Section 3.3.3.2) to determine a realistic, teacher- and learner-oriented setting in which LBML would be used. The design contained a procedure with a sample of potential participants that represented a typical class structure and size. The experiment revealed that clear instructions for both teachers and students were necessary to obtain valid results and that the students needed to demonstrate a basic willingness and motivation to do such an experiment. As far as the procedure is concerned, small changes are needed regarding the timing of the examination survey. This should be done before the students receive the exam results and not afterwards. Furthermore, to pay attention to the teacher's workload, further functionality was implemented that emulated the module on the OMLETH-Player using the OMLETH-Creator.

4.1.5 Variables and instruments

Students were assigned anonymous usernames for the experimental technologies and the questionnaires. The following approaches were taken to measure the performance of the various research questions and hypothesis:

For research question **RQ4.1,** teachers were provided insights through a semi-structured interview conducted at the end of the study.

For research question **RQ4.2**, a statistical and map-based visual analysis of movement trajectories was performed, and a post-experiment questionnaire was used to retrieve the learners' perception of usability regarding positioning and web access. The questionnaire responses are ratings and are scaled with a set of five items on a agree-disagree Likert-type scale.

For hypothesis **H4.3**, the dependent variable was the classroom examination grade as a performance assessment expressed gradually in corresponding numbers from 1 to 6. The best grade is 6, 1 is the worst, and grade 4 means passed and implies a sufficient performance according to the minimum requirements. The grading schemes are determined by the teacher but are commonly rounded to two decimal places or quarter, half, or whole grades.

For research question **RQ4.4,** further dependent variables such as self-assessment of understanding, motivation, and attitude of the same students over repeated observations were collected using questionnaires. The responses are ratings and are scaled with a set of five items on a agree-disagree Likert-type scale.

For research question **RQ4.5**, further dependent variables such as the self-assessment of situation and content recall over repeated observations were collected via questionnaires. The responses are ratings and are scaled with a set of 5 items on a agree-disagree Likert-type scale.

Self-assessment

Self-assessment is a learner-centered learning strategy of formative assessment in which "*students reflect on the quality of their work, assess the extent to which they have achieved explicitly self-imposed goals and revise these goals accordingly*" (Andrade & Valtcheva, 2009, p. 13). Therefore, the assessment itself can have an impact on the learning process and must be taken into account when evaluating follow-up activities. To ensure the quality of the research, the criteria should meet the objectivity, reliability, and validity. To achieve the independence of the relationship between the students and their responses (objectivity), multiple-choice questions, including few open answer questions at the end of the questionnaires, were chosen. To achieve consistency of results (reliability), some constructs (usability, affection, recall) were recorded with several items, taking into account the number of items that should not exceed 2 minutes for each survey according to the insights of the preliminary study. To ensure that students understand the survey answers well and how they are evaluated (validity), students were properly introduced to the learning goals and the meaning of the survey responses. To reinforce this meaning, the survey responses were expressed in the below stated five-item Likert-type scale, enhanced by numbers in brackets representing the school grades:

- Disagree Strongly (2)
- Disagree (3)
- Agree Slightly (4)
- Agree (5)
- Agree Strongly (6)

In the Swiss school context, a grade 1 mark is hardly used in practice if there is any performance to measure. Typically, the lowest grades are awarded a grade 2, which is why it holds the value of “Disagree strongly”. A grade 4 reflects the minimum requirement to pass a test and is therefore compared to the response type, “Agree Slightly” instead of the common Likert-scale value, “Neutral”. Grade 6 depicts a perfect performance and is associated with the “Agree Strongly”. The school grading scheme did not fit with the Likert “Disagree moderately”.

4.1.6 Procedure

The experimental study lasted four months. Figure 27 depicts the procedure of the experimental study.

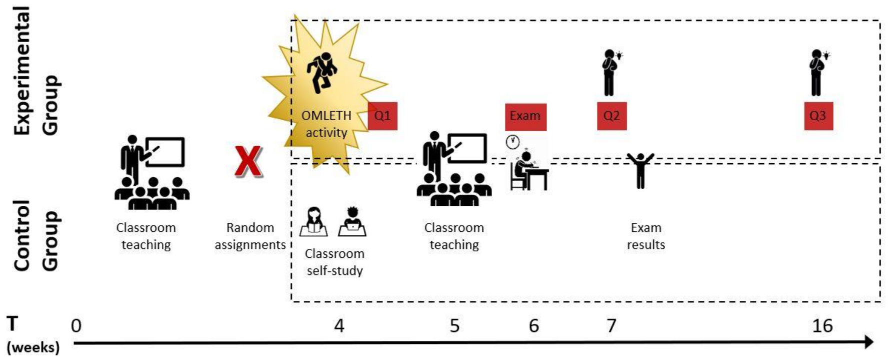


Figure 27 The procedure for the experimental study.

Weeks 0–4: Classroom teaching and preparation of the LBML activity

During this period, teachers were instructed on how to use and create an LBML module with OMLETH. The module consisted of four learning stations with multimedia content, embedded and linked content from external web services, and a WhatsApp chat. During these four weeks, the teachers had to create an OMLETH trail as LBML double-lesson for the experimental group. Students were classified by the teacher based on their exam grades from the last two years and randomly divided into two equally strong groups: the experimental group and the control group.

Week 4: Experiment and Questionnaire (Q1)

The experimental group of 56 students was required to complete the OMLETH activity as a double LBML lesson (90 minutes) in the school neighborhood using personal mobile devices (Bring Your Own Device (BYOD)). The control group of 51 students had the opportunity to work independently without teachers on the same instructional content provided to the experimental group as well as on the previous week's material.

When the experimental group finished the LBML lesson, they undertook the survey Q1 (see Table 6) to reflect on their learning progress and to review the usability of OMLETH. The original survey can be found in Appendix Section II.

Research Question	Survey question	Type of response
RQ4.4	Q1.1: My understanding: Thanks to the learning module, I understood the topic better than if I had dealt with it only in the classroom.	Five-item Likert scale
	Q1.2: My motivation: Thanks to the learning module, my motivation on the topic is now higher than if I had dealt with it only in the classroom.	
	Q1.3: My attitude: Through the learning module, I will, in the future, be more committed to the topic than if I had dealt with it only in the classroom.	
RQ4.2	Q1.4: Positioning: The positioning in OMLETH worked in a satisfying way to access the learning elements.	Five-item Likert scale
	Q1.5: Internet access: The online maps and learning elements in OMLETH were good enough to access this information.	
	Q1.6: OMLETH operated at a stable level.	
RQ4.4	Q1.7: In general, the OMLETH approach added value compared to classroom instruction.	Five-item Likert scale
RQ4.2	Q1.8: Remarks about weather, disruption, special experiences:	Open answer

Table 6 Questionnaire (Q1) for the experimental group.

Week 5: Classroom teaching (Debriefing of week 4)

After Q1 in the fifth week, teachers should have a two-part debriefing in the classroom with both groups together during a lesson. The first part consisted of a short review of the LBML activity or classroom self-study separately within the groups. The subgroups of the experimental group should have access to the web-app OMLETH-Viewer and all external systems used during the activity. After this group-specific review, the teacher was invited to discuss the LBML activities in plenary. For example, individual groups of students could use an OMLETH viewer to present their activity in the plenary, what they discovered, how they perceived it, and what they learned from it. If necessary, the teacher should intervene to correct any misconceptions or misunderstandings.

Week 6: Exam

At the end of the teaching unit, both groups undertook the same in-class examination, which was managed by the teachers.

Week 7: Questionnaire (Q2)

One week after the examination, both groups were required to complete the survey Q2 (see Table 7) before the grade results were received. The original survey can be found in Appendix Section II.

Research Question	Survey question	Type of response
RQ4.4	Q2.1: I enjoyed the module.	Five-item Likert scale
	Q2.2: I enjoyed learning on my mobile phone.	
	Q2.3: The learning approach of the trail is innovative.	
RQ4.5	Q2.4: I could explain the content of all the learning stations completed on the trail.	Three-item scale
RQ4.4	Q2.5: The experiences and lessons learned on the trail were supportive of learning for the examination.	Five-item Likert scale
	Q2.6: The module increased my motivation to learn for the examination.	
	Q2.7: Remarks about the trail:	Open answer
RQ4.4	Q2.81: My understanding: I currently understand the topic well.	Five-item Likert scale
	Q2.82: My motivation: My motivation for the subject is basically good at the moment.	
	Q2.83: My attitude: In the future, I would like to commit myself more strongly to the topic.	
	Q2.9: Remarks about my self-assessment:	Open answer

Table 7 Questionnaire (Q2) after the examination.

The survey was divided into two parts. The first part was for the experimental group (Q2.1 - Q2.7), who had to once more reflect on the LBML lesson and on the LBML as a learning activity. The second part was for both groups (Q2.81 - Q2.9) to assess their current state of understanding, motivation, and attitude. After taking the survey Q2, the students received the examination results.

Week 16: Questionnaire (Q3)

Three months after the exam, both groups needed to respond to survey Q3 (see Table 8). The original survey can be found in Appendix Section II. The survey was again divided into two parts. Both groups were asked to note their general perception towards the school subject (Q3.1), interest in the topic (Q3.2), and the current state of understanding, motivation, and attitude towards the learning subject (Q3.10 – Q3.14) while the experimental group had to reflect on the Q2 period LBML lesson and examination (Q3.31 – Q3.52).

Research Question	Survey question	Type of response
RQ4.4	Q3.1: School subject: Basically, I have a positive attitude towards this school subject.	Five-item Likert scale
	Q3.2: My interest before the first school lesson: My interest in the topic before the first lesson was good.	
RQ4.5	Q3.31: I could explain the content of all the learning stations completed on the trail.	Three items scale
	Q3.32: The experiences from the trail are helpful for my expertise on the topic.	Five-item Likert scale
	Q3.33: If I were to meet the learning content of the module again with a concrete example, I would immediately think of the module itself.	
RQ4.4	Q3.4: I would like to elaborate on a topic once again with location-based examples and my own smartphone.	Five-item Likert scale
	Q3.51: If the examination were also designed as such a module, I would actively explore similar examples in everyday life.	
	Q3.52: If the examination were also designed as such a module, I would repeat the learning module.	
RQ4.4	Q3.10: My understanding: I understand the topic well at this point in time.	Five-item Likert scale
	Q3.11: My motivation: My motivation for the subject is good at the moment.	
	Q3.13: My attitude: In the future, I would like to commit myself more strongly to the topic.	
	Q3.14: Closing remarks:	Open answers

Table 8 Questionnaire (Q3) three months after the examination.

A challenge of this longitudinal study was the issue of participant motivation. To obtain valid results, participants needed to remain sufficiently motivated to carry out the first, second, and third surveys objectively. This challenge was heightened by the absence of a monetary reward or gift-in-kind for the students.

4.1.7 Analysis

For the analysis of RQ4.1, the teachers' interview responses on the planning and preparation of the LBML design were evaluated by means of structured qualitative experience reports of each LBML lesson. The reports included the learning objectives, the individual preparation steps, and the amount of workload in comparison to regular teaching workload.

To study RQ4.2, a comparison of movement analytics and learner perceptions was made using descriptive statistics and visual analytics. Several interaction measurements, such as the amount of active time use of the OMLETH-Player, position accuracy, and user interactions to request access to the learning content were collected. The active time use of the OMLETH-Player,, defined here by the duration of the browser session, was achieved by passively tracking all students by retrieving position data including accuracy information. The active time use of the OMLETH-Player, could be interrupted through the closing of the browser window, owing to the learner opening another mobile app or switching the phone off. In this study, in addition to oral instruction, the students were informed about position tracking without the switch-off options to ensure data collection. The active user interaction was surveyed by examining the clicks of the learning station requests that were necessary to access the learning content. The hypothesis was that the fewer clicks, the higher the overall satisfaction, which could be gathered from the questionnaire Q1.

To examine H4.3 with the summative assessment and to carry out valid inferential statistics, the two groups were divided according to their geography grades from the previous two years. To analyze the results and to respect the cluster effects of the classes, teachers, and schools, R (R Core Team, 2017) with lmerTest (Kuznetsova, Brockhoff, & Christensen, 2017) was used to perform linear mixed-effects (LME) analysis of the LBML lesson as the independent variable. The analysis was conducted under the assumption that the LBML activity was assumed to be a fixed effect and class, teacher and school as random effects.

To evaluate RQ4.4 and RQ4.5, inferential statistics were used. If none of the random effects (classes, teachers, and schools) proved significant for the examination outcome (all $ps > .05$), the dependent variables of RQ4.4 and RQ4.5 from the within-subjects designs were compared with a one-way ANOVA and from the between-subjects designs with the two-sample unpaired t-test. A review by the teachers established the validity of the trajectories' data and the questionnaire's data.

4.2 Results

This section presents the study results, i.e., the teaching preparation, the trail observations of six classes, the summative assessment through the examination, the students' reflections on surveys after the LBML activity, after the examination, and in a long-term observation.

4.2.1 RQ4.1 Teaching location-based mobile learning

To understand how teachers plan and prepare when developing and teaching an LBML lesson, a semi-structured interview after the study with each of the teachers was conducted.

4.2.1.1 Results of the teachers' planning and preparation

Teachers' personal experiences before the study

The results are based on a semi-structured interview which contained questions about the strategies for planning and developing the LBML lesson (see Appendix III). The interview conversations revealed that all the teachers had extensive knowledge of and experience in conducting fieldtrips and excursions and therefore knew how to apply the learning content of geography in real-world contexts. They also knew how to support the core curricula of the EDK. Teachers argued in favor of conducting field trips for three reasons:

- Linking educational content with social activities and independent, experiential learning.
- Practicing map reading and wayfinding to foster spatial awareness and spatial cognition.
- Applying subject-based skills in authentic situations to promote problem-based learning.

When discussing pre-field trip preparation, the teachers stated that field trips and museum visits are always time-consuming and require long-term planning. Regarding the lesson planning structure, the first steps are to define the learning objectives clearly. This is followed by an on-site visit as an inspection, in order to test teaching concepts that can be used to explore the learning content with the greatest possible degree of learner agency regarding procedure and solution. The preparation of an excursion is, therefore, an elaborate process and takes significantly more time than a regular classroom lesson.

Regarding the use of technology, teachers noted that they had not implemented an LBML activity for teaching before. However, the teachers had experience in classroom-based GIS learning and GPS in the field, and in informal learning activities with GIS/GPS such as geocaching. Consequently, the teachers were interested in participating in the study to learn a new teaching approach and technology.

Table 9 provides a summary of the teaching preparation. Teachers from each school created an LBML lesson with a specific topic in their school's neighborhood. Each lesson was planned for 90 minutes (a double lesson) and included a set of learning stations, which varied between eight stations in Zürich and twelve stations in Beromünster. Teachers chose different levels of inquiry, from structured activities according to a specific sequential order of tasks, such as guided trails, and open activities, including freely chosen tasks, such as rallies or scavenger hunts. The teachers also decided what approaches and additional technologies they chose. The pedagogies were allowed to cover from deductive approaches with transfer learning and recalling of classroom theories to inductive methods with investigations and pattern finding exercises, or a mixture of both. Additional technologies included separate hardware for environmental measurements and external services such as tools for location diaries, data collections or multimedia content, etc.

Schools	Topic	Number of learning stations	Task order	Pedagogy	Technology	Workload in hours
Beromünster	Climate elements	12	No sequence	Inquiry	Scientific/Instruments	5
Zürich	Rock types	8	No sequence	Reproduction, gamification	Surveys with pointsification, one location-based survey	9
Olten	Settlement development	9	Sequence	Reproduction and inquiry	Podcast, video	12
Aarau	Urban development	6	Sequence	Reproduction and inquiry	Surveys, one location-based survey	26

Table 9 Metadata from the LBML lessons regarding content topic, number of learning stations (tasks), order of tasks, pedagogy, additional technology, and workload to develop the lesson

Table 9 shows the total workload in hours for the implementation of the LBML lessons. Details contain the learning goals, the concepts, and the implementation process, which were gathered through the semi-structured survey, and described in the next subsections.

4.2.1.1.1 Beromünster Study

The geography teacher from Beromünster aimed to lead a trail experience on climatic elements (such as humidity, radiation, temperature, clouds, and air pressure), techniques for their measurement, and the interrelation of the elements. Apart from subjective knowledge, the students had no formal prior knowledge of climatic elements. The goal of the LBML lesson was for students to construct knowledge about abstract learning content with observable phenomena in the school environment:

- Subject-based skills were needed to experiment with natural materials, measuring instruments, and scientific measurement methods.
- Spatial awareness and map reading skills were necessary for wayfinding and for locating suitable surfaces for the measurements.
- Soft skills were required to express new ideas, as well as personal opinions and attitudes toward location-based problems, and to work independently in groups of three.

The examination tested subject-based skills only. The grade accounted for one-third of the semester grade, which, in turn, counted for the graduation grade (Matura).

The teaching strategy of the module

The teacher's strategy was to design an LBML activity with an unspecified sequence of twelve mandatory tasks at the learning stations. Each task introduced a short theoretical description of the climatic element plus an application task. The application task included the search for typical objects with certain surface properties and the ability to scientifically measure climatic elements. The measuring instruments included environmental sensors in heavy boxes, which were previously placed at the learning stations by the teacher. The students had no prior knowledge in using these instruments and therefore, part of the teacher's key question whether the mode of inquiry would work. An essential prerequisite for the LBML activity was sufficient sunlight for the radiation task, which involved measuring the diffuse reflection of solar radiation, known as Albedo.

To save the results and document the discoveries, students used the mobile Personal Learning Environment (PLE) app of the school's learning management system (LMS). The trail did not consider the formal exchange among students or teachers using a communication service because the primary goal was for students to be able to solve the tasks independently without teacher assistance. However, private group chats among students existed and were tolerated.

The development of the module

The teacher usually needs one or two hours to prepare a new regular classroom lesson without the introduction of new technology. For the LBML trail, he took five hours to develop the module. The main work was the creation of the task and finding suitable locations around the school with typical surfaces to be able to use the context-dependent measurements within the total available time of two lessons. The steps were:

Step	Description	Workload in hours
1	Reviewing the existing teaching material.	0.5
2	*In-situ* exploration to search for available measuring objects on-site, testing of the measuring instruments, and recording of considerations and decisions in handwritten notes.	2.5
4	Calculating a possible route based on the available time with the OMLETH route assistant and creating the OMLETH learning stations based on the notes from the *in-situ* exploration.	1.5
5	Testing and modifying the text output with the OMLETH emulator.	0.5

For the control group, the teacher did not have to invest any extra effort because the students could use the existing teaching materials and self-study. If the LBML lesson were to be executed without the LBML technology, the teacher expected the same workload for a single procedure due to the worksheet production and plots.

4.2.1.1.2 Zürich 1 and 2 Studies

Two geography teachers from the Freies Gymnasium Zürich planned an experience involving ten rock types in the school's neighborhood. The students were taught extensively about the composition and properties of igneous, metamorphic, and sedimentary rocks, the fragments of which were physically in the classroom, which students could then hold. The students' goal in this LBML lesson was to reproduce and apply existing knowledge in a familiar environment, such as in the school neighborhood, the park, and the lakeside area. To achieve this goal, students needed:

- Subject-based skills to explore, sort, and describe fragments of rock artifacts and to prove the findings by taking pictures or recording videos.
- Spatial awareness and map reading skills for wayfinding and to locate the rocks based on a description.
- Soft skills to express new ideas, as well as personal opinions and attitudes toward location-based problems, and to work independently in groups of two.

The examination tested subject-based skills only, and the grade accounted for one-third of the semester grade.

The concept of the module

The design of the LBML lesson was that of a geogame. It had an unspecified sequence of eight learning stations and two multimedia stations. The overall task was to achieve a minimum number of points that were earned through several quests at the learning stations. The content contained the tasks in OMLETH, and hyperlinks led to surveys on the school's LMS. The surveys included questions about a type of rock to be found using the geocaching. After students discovered and identified the rock, they had to assign it to one of four alternatives and give qualitative reasons for their choice. A short video provided hints about the specific type of the rock fragments. If the group of students chose the correct answer, they received points dependent on the complexity of the task. One question at a rocky shore of the lake contained a location-based survey with a mobile app in which students had to map a specific rock type. Two questions included a quest in which the students had to explain the history of the rock type in a short video.

To store the results and to document their discoveries and reflections, students used the linked survey apps at the learning station of the school LMS. The geogame did not consider the formal exchange between students or teachers. The students were connected through a class chat.

The development of the module

Teachers (T1 and T2) reported that they usually require two to three hours to prepare a new regular classroom lesson, which for T2 mostly contains web GIS in the classroom or mobile GIS in the field while T1 preferred to use traditional media. For the geogame, the teachers shared the planning and preparation work. It took nine hours to prepare the module. Zürich 1 (T1) teacher primarily developed the concept, and Zürich 2 (T2) teacher created the technological part. The main work, however, was field work. The geogame preparation steps were:

Step	Description	Workload in hours
1	Co-determining the phase of exercises suitable for the geogame (T1 and T2)	0.5
2	Co-determining the approximate route with the base maps and the OMLETH route assistant of the OMLETH-Creator (T1 and T2)	0.5
3	Creating a prototype storyline (T1)	0.5
4	Co-exploration of the school's surroundings, searching for prominent rock types along the virtual route and recording the discoveries and *in-situ* decisions with a location-based survey app (T1 and T2)	4
5	Creating the lesson plan and questions in a shared Word document (T1 and T2)	3
6	Transferring the questions to the school's LMS and OMLETH-Creator and testing with the OMLETH emulator (T2)	0.5

For the control group, teachers did not have to invest any extra effort in lesson preparation because the students could self-study using the fragments of the rocks in the school's inventory. If the LBML lesson were to be executed without the LBML technology, the teachers expected a 20% workload increase for a single procedure due to the worksheet production and plots, and the more significant time required for the students to post-process the mapping tasks.

4.2.1.1.3 Olten 1 and 2 Studies

Kantonschule Olten's (KSO) geography teacher identified the settlement development in the oldest district around Olten's railway station as the experience site. The students learned in the classroom about the theories of settlement during the period of industrialization. The students' goal was to reproduce and apply existing knowledge in a familiar environment by using:

- Subject-based skills to compare, analyze, and evaluate the settlement development of the situation under study and to describe contextual factors about features of settlements and the settlements' spatial distribution.
- Spatial awareness and map reading skills for wayfinding and to compare and evaluate story examples with historical web maps and the physical context.
- Soft skills to express new ideas, as well as personal opinions and attitudes toward past and future aspects of settlement development, and to work independently in groups of two.

Subject-based skills were the primary focus of the examination. However, the examination also addressed soft skills, such as personal opinions about the settlement development scenarios. The grade accounted for one-third of the semester grade.

The LBML lesson was designed as a trail with a sequential order of nine learning stations and two photo stations. The content was designed to incorporate storytelling and rich digital media with radio or television reports. Context analysis was supported by historical interactive maps of the Federal Office of Topography, which stimulated critical thinking. Two learning tasks were set that included direct interaction with residents where possible.

Students used personal mobile note apps and took photos to store the results and to document their tasks, special findings, and reflections. Tasks were set that required intensive exchange between students of the same group. An exchange with the teacher was not considered, why no extra communication service was implemented.

The development of the module

The teacher usually requires one hour to prepare a new regular classroom lesson. For the trail, he needed twelve hours to develop the module. The primary tasks were to research good teaching examples around the railway station and to conduct additional research to locate appropriate materials, such as old pictures and maps. The work steps were as follows:

Step	Description	Workload in hours
1	On-site exploration based on previous knowledge about interesting places, testing of the positioning, and web access with the OMLETH-Player, and recording of decisions in handwritten notes.	4
2	Creation of the learning stations' perimeter in OMLETH-Creator.	0.5
3	Reviewing the existing teaching material and creating and organizing the questions in word processor software.	5
4	Transfering the resulting questions from the word processor software to OMLETH's learning stations.	1.5
5	Modifying the complexity of some questions based on the route calculation with OMLETH's route assistant to align the expected time use.	0.5
6	Testing and adjusting the text output with the OMLETH emulator.	0.5

For the control group, the teacher created an e-learning course with the same examples used in the LBML trail that the students could use for self-study. If the LBML lesson were to be executed without the LBML technology, the teacher stated he would use a completely different teaching strategy, which is not comparable to the LBML approach, yet would require a similar investment of time.

4.2.1.1.4 Aarau Study

Two geography teachers from the Alte Kantonsschule Aarau aimed to experience urban development in the city of Aarau. The students learned in the classroom about the theories of urban development during the last 200 years. The students' goal was to reproduce and apply existing knowledge in a familiar environment by using:

- Subject-based skills to explore, observe, analyze, map phenomena based on theories, and solve open-ended problems *in situ*.
- Spatial awareness and map reading skills for wayfinding and for perceiving and analyzing the spatial expansion of the urban phenomena *in situ*.

- Soft skills to express new ideas and demonstrate critical thinking, as well as to reflect on personal attitudes toward location-based problems, and to work independently in groups of three.

The examination tested subject-based skills only, and the grade accounted for one-third of the semester grade.

The LBML lesson was designed as a trail with a sequential order of six learning stations. The content was designed to incorporate storytelling, and many learning stations contained open or closed questions in linked online surveys. A location-based survey was used to observe and capture features along a street. The last station, on top of the school building, included spatial perception tasks using the overview map attached to the railing. The documentation of each task's results and special findings was conducted at the learning stations through the web-based surveys. Conversation between groups was requested, but without using digital communication methods. The embedded communication service was available in case of an emergency only, and not for formal exchange.

The development of the module

Teacher B (TB) usually requires one hour to prepare a new regular classroom lesson, which rarely contains technology. Teacher A (TA) is specialized in didactic methods in Geography and is experienced in developing lessons using mobile technology. However, for the preparation time, she needs up to four hours per lesson. For the geogame, the teachers conducted the preparation together. They took 26 hours in total to prepare the LBML lesson. The primary tasks were field work - to find authentic and exciting examples - and web-based research. The steps they took in lesson development were:

Step	Description	Workload in hours
1	Reviewing the existing teaching material (TB).	2
2	Co-exploring research sites, including suitable routes to locate them, and recording discoveries in handwritten notes (TA and TB).	12
3	Creating and arranging the questions in text documents and creating online surveys (TA).	6
4	Transferring the resulting questions to OMLETH (TA) and verifying the trail with OMLETH's route assistant (TA and TB).	1.5
5	Co-testing the lesson on-site (TA and TB).	3
6	Modifying the content of selected questions and changing the perimeter of stations due to pedagogical reasons (TA).	0.5
7	Testing the lesson on site again (TA).	1

For the control group, no further effort was required on the part of the teachers as the students used existing teaching materials to self-study. If the LBML lesson were to be executed without the LBML technology, the teachers expected a 30% lower workload for a single procedure because time-consuming in-situ testing would not be needed.

4.2.1.2 Findings

The learning goals, teaching strategies, and preparation steps findings are as follows:

F4.1.1: Regarding learning objectives, the teachers emphasized the promotion of *skills* such as exploring, observing, measuring, analyzing, or mapping the learning content. Spatial awareness and map reading skills were used for wayfinding and for analyzing the contextual phenomena in situ, at times combined with digital material such as maps. *Spatial reasoning* skills were needed to tackle learning tasks at learning stations in combination with the cognitive objectives. *Soft skills* were required in the cooperation within the group with conversation, self-motivation and the independent management and distribution of tasks in groups of two or three students.

F4.1.2: Three LBML lessons contained deductive approaches with exercises incorporating previous teaching sequences in the classroom. Beromünster's lesson included an inductive teaching approach in which students had to construct laws and theories based on experimenting with the measuring instruments. Due to the self-regulated learning approach used by all teachers, no module contained an active communication concept involving communication and exchange experiences between students and teachers, nor between peers of different groups.

F4.1.3: The teaching preparation took between five and thirteen hours per teacher. This time allowance was at least twice as long as classroom preparation but was similar to the time needed when preparing a new lesson as a traditional field trip. Aarau noted that traditional field trips require less testing, and Zürich said that the production and plot with paper material would require additional time to conduct, versus a conventional field trip.

F4.1.4: Since the participating teachers all taught the subject of geography and completed didactic training in the study of geography, the general procedure for planning and preparing the LBML lessons was linked to the didactical approaches of geography (Rinschede & Sigmund, 2020). However, the teaching content was always different and the procedure of creating an LBML was new for everyone and therefore subject to countless contexts (location, learning objectives, time, methodologies, technologies, teaching experience, etc.). Nevertheless, following the teacher interviews, some agreement was reached on the minimum steps required and the workload (how much work is needed to prepare a double lesson). The agreement led to a model which is divided into five categories:

Step	Description	Workload in hours
1	The requirements analysis for the choice of topic and the general learning objectives (subject-based goals and soft skills).	> 0.5
2	Determining the approximate spatial extent of the area by inspecting online maps and by sketching a potential route in OMLETH-Creator.	> 0.5
3	*In-situ* exploration to become aware of the available places and the characteristic of the content, drafting the polygons of the learning stations with the OMLETH-Creator using a tablet and taking notes on paper material.	> 2 (without travel)
4	The creation of the OMLETH learning stations and external systems and deciding the collaboration mode.	> 1.5
5	Testing, modifying, and re-testing the text entries with the OMLETH emulator.	> 0.5

4.2.2 RQ4.2 Movement analytics and learners' perceptions

The movement trajectories were collected while the students were active using OMLETH during the LBML lesson. To resolve the question if movement analytics can explain students' usability perception regarding positioning and web access, a comparison of map-based visual analytics (VA) results of the trajectories with the usability feedback from the questionnaire Q1 was examined (see Table 6). The results of the trajectory analytics are described in Subsection 4.2.2.1, and the results of the usability feedback are detailed in Subsection 4.2.2.2.

To exclude some of the contextual effects of research question RQ4.2 on the evaluation of usability of this section and of research question RQ4.4 on the self-assessment of learning progress of Section 4.2.4, the perception of the environmental context was surveyed by direct observation and student feedback from the comments of Q1.8 of the Q1 survey.

Table 10 summarizes the context information such as the weather, temperature, reported disruptions, and special comments concerning student's satisfaction.

Experiments (number of occurrences)	**Weather**	**Reported disruptions**	**Comments (Q1.8)** n=negative, p = positive
Beromünster (9)	18°C, cloudy		1 n
Zürich 1 (8)	18°C, sunny		1 n
Zürich 2 (7)	7°C, sunny, windchill		2 n
Olten 1 (7)	10°C, sunny		1 p, 1 n
Olten 2 (8)	10°C, sunny	Railway noise	2 p
Aarau (17)	9°C, sunny, windchill		3 p and 4 n

Table 10 Metadata of the environmental and psychological context.

All experiments were conducted in dry conditions. Beromünster and Zürich 1 had the highest temperature, at a pleasant 18 degrees Celsius, when doing their experiments. Zürich 2 and Aarau had temperatures of below 10 degrees and an unpleasant wind chill. In the voluntary and open question Q1.8 within questionnaire Q1, students were asked for general feedback. Ten of 56 students gave feedback about the weather and technological context, which concerned students' satisfaction. In Beromünster someone reported about the need for some technical improvements and in Zürich 1 someone complained because the app did not work well. Two students from Zürich 2 reported that they had no interest in completing the trail in the cold. A student from Olten 1 reported that she enjoyed that kind of experience very much while another student was distracted by the noise at the learning stations near the railway station. A student from Olten 2 provided positive feedback saying they enjoyed the mobile outdoor activity and found it very exciting in the beautiful weather. Three students from Aarau gave similar feedback like Zürich 2, in that the cold challenged both the user and the phone's battery, especially when the surveys had to be completed on-site with students having ungloved hands. Another student was very bored by the activity, while three students were very enthusiastic about the change of learning outside.

4.2.2.1 Results of the statistical analysis of the trajectories

An indicator of good usability is that technical interaction is effective, efficient, and satisfactory. Therefore, several interaction measurements were surveyed, such as the amount of active use of the OMLETH-Player, the position accuracy, and the request to access the learning content.

Table 11 depicts these measurements per experiment in the upper half as follows: the mean active time use in percent of the OMLETH-Player throughout the double-lesson, the median of the number of clicks on the station request button according to the number of pupils and number of learning stations, and the median positional accuracy in meters. The lower half shows the number of learning stations per module, the number of active students using the OMLETH-Player web app, and the size of the students' groups to provide context to the measurement values.

Mean active use

The mean active use throughout the double-lesson was captured by the pupil's phone position recording at intervals of eight seconds when the pupil was actively using the OMLETH-Player.

Table 11 shows that Beromünster had an average use of 65% per pupil, while Zürich 2 showed an active use of 23% within the 90 minutes of the double lesson.

Median of station requests

The median of the station request was normalized based on the number of learning stations and the number of active students using the OMLETH-Player. In terms of great usability (efficiency), an optimal value would be one request per pupil and station. Beromünster required a median of 4.2 requests per station to access the learning station, while Aarau used a median of only 1.5 requests. Beromünster and Zürich 2 had the largest heterogeneity, with a standard deviation score of 1.8. In contrast, Olten 2 achieved the lowest heterogeneity with 0.3, which means that all participants in the groups showed similar behavior and asked for the station contents with similar frequency.

Experiments (number of occurrences)	**Mean active use of OMLETH** (in %)	**Median of the number of station requests per pupil and per station** (in clicks) (mean, standard deviation, minimum, and maximum value)	**Median accuracy of the positions (raw data)** (in meters) (mean, standard deviation, minimum, and maximum value)
Beromünster (9)	65%	4.2 (MEAN=4.4, SD=1.8, MIN=1.2, MAX=6.6)	6 (MEAN=27, SD=106, MIN=3, MAX=3103)
Zürich 1 (8)	26%	1.6 (MEAN=1.8, SD=1.4, MIN=0.1, MAX=6.6)	10 (MEAN=110, SD=341, MIN=3, MAX=6332)
Zürich 2 (7)	23%	1.7 (MEAN=4.4, SD=1.8, MIN=0.1, MAX=4.6)	11 (MEAN=396, SD=1899, MIN=3, MAX=19394)
Olten 1 (7)	32%	3.9 (MEAN=3.9, SD=1.5, MIN=2.1, MAX=5.8)	12 (MEAN=77, SD=245, MIN=3, MAX=2978)
Olten 2 (8)	42%	2.3 (MEAN=2.2, SD=0.3, MIN=1.8, MAX=2.7)	10 (MEAN=46, SD=178, MIN=2, MAX=3346)
Aarau (17)	33%	1.5 (MEAN=2.8, SD=1.4, MIN=1.3, MAX=6.8)	10 (MEAN=32, SD=160, MIN=2, MAX=2700)
Experiments (number of occurrences)	**Number of learning stations**	**Group size**	**Number of active students**
Beromünster (8)	12	3	9
Zürich 1 (7)	8	2	8
Zürich 2 (4)	8	2	7
Olten 1 (4)	9	2	7
Olten 2 (10)	9	2	8
Aarau (18)	6	3	11

Table 11 Statistical results of the user data per experiment with the mean of the active time use per experiment, the median of station requests, and the median of the positional accuracy

Median position accuracy

The position accuracy of the raw data revealed by the Geolocation API indicates that all median values showed an expected accuracy of mobile phone positioning between 6 meters (Beromünster) and 12 meters (Olten 1). However, all the six experiments contained few but partly very large outliers (several kilometers) as well.

Visual analytics of the 2D maps

The VA of the movement trajectories focused on position accuracy, station request issues, and overall problems visualizing the raw data on 2D and 3D base maps. The 2D map contains the movement trajectories as collections of point representations that sent the positions at regular intervals of eight seconds when OMLETH was used actively (point cloud; see Figure 28 (top)). Colors that represent the individual pupil show the differentiation of the trajectories. The 2D map also contains the learning stations as polygons and the positions where the pupil requested the learning stations as large point symbols. Based on the results of the click interaction, the symbols are displayed as different colors:

Light green symbols represent the successful requests of learning stations when the pupil was closer than 10 meters. The user received access to the learning task.

Blue symbols represent the unresolved error requests when the user was closer than 10 meters to two learning stations at the same time because the learning station did not take into account the minimum distance of 20 meters to the next one.

Red symbols represent the failed requests when no learning station was available within 10 meters.

The red dashed line is the virtual route planned by the teacher. This information was not available for the students in OMLETH-Player's map interface.

Visual analytics of the 3D maps

The VA on the 3D map (see Figure 28 (bottom)) represent not only space but also time. The perspective view of a three-dimensional representation visualizes the course of time in the vertical dimension over the underlying map. The temporal axis is oriented from the bottom to the top, starting from the first space-time position. This visualization helps to detect speed as the slope of the movement trajectory and the differentiation of the multiple geographically related or unrelated students. Unrelated students are spatially, temporally, or spatio-temporally separated from each other, which is shown as notable gaps between the tracks. At the same time, related learners are spatio-temporally connected, moving in groups, and are shown as a cluster.

4.2.2.1.1 Beromünster

Figure 28 depicts the allocation of the twelve learning stations for the experiment in Beromünster and the trajectories of the students on the school ground, as shown in the 2D and 3D maps. The students started the trail at the school's main building (white rectangle, top picture) in groups of three. The trajectories (top picture) show no trace of students leaving school. Thus, it can be assumed that nobody abused the situation, had serious difficulties with orientation, or with finding their way to a learning station.

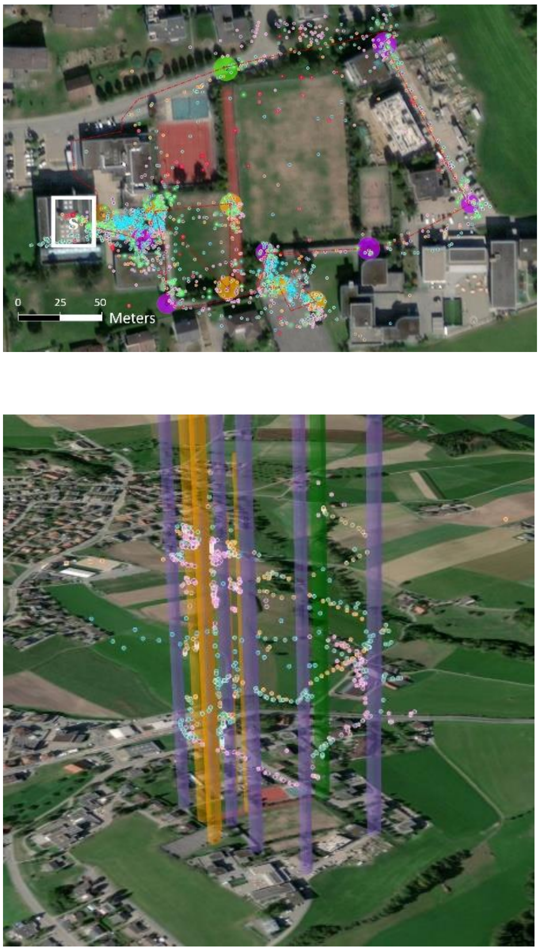


Figure 28 Nine students in groups of three executing the experiment in Beromünster, differentiated by color, and visualized as point clouds.

(Top picture) 2D map, including the start (white rectangle), the learning stations as circular polygons, the learning station requests, and the red dashed planned path of the teacher.
(Bottom picture) 3D map, including the learning stations as vertical columns.
(Software: © OMLETH; base map: © Esri).

The map shows that students located the learning stations by way of the fastest route possible, if environmentally possible. For example, several students crossed the different football fields instead of walking along the paths. The purple learning stations, which are diametrically opposite to the starting point (see white rectangle, top picture), were all reached via the side-road as expected by the teacher. The routes anticipated by the teacher and not visible for the students represent the red dashed line. Regarding incident analysis, the map in Figure 28 (top picture) shows two blue-colored dense point clouds of unresolved requests. The first region is close to the school's main building, and the second is at the bottom center of the map. The reason for both incidents was that the distance between two learning stations was less than twenty meters due to the design imposed by the teacher's construction. The light green symbols over or at each learning station indicate that the learning stations were well accessed.

Figure 28 (bottom picture) shows tightly coupled trajectories of individual students. This indicates that the group members were physically close and moved close together at a walking speed of 3-5 km/h from one station to the next. The individual groups usually show up as unrelated entities representing a vertical gap between the trajectories. The learning stations at the side-road showed a difference of half an hour. The lack of obvious data gaps due to geography and regular positioning of the trajectories indicates that web access must have been consistently available, and GPS positioning worked fine. The semi-structured interview with the teacher after the study revealed that the weather was too cloudy to run the learning stations with the albedo calculation. These stations required a minimum amount of sunlight to observe the expected difference in measurement between the materials.

4.2.2.1.2 Zürich Class 1

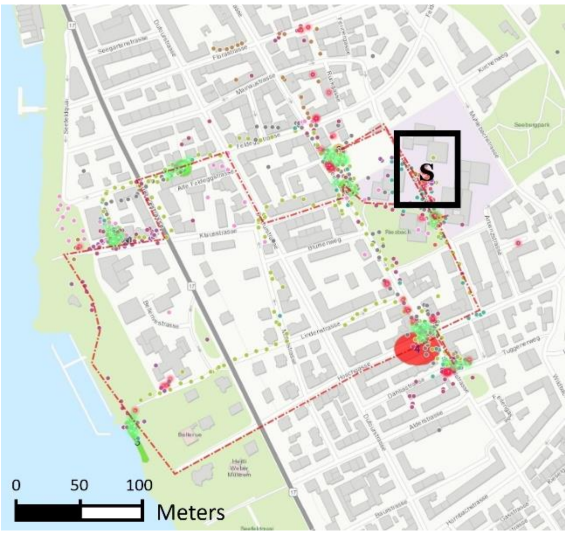


Figure 29 2D map with eight students from Zürich 1 in groups of two executing the experiment, differentiated by color, and visualized as point clouds,

The map includes the start (black rectangle), the learning stations as circular polygons, the learning station requests, and the red dashed planned path of the teacher
(Software: © OMLETH; base map: © Esri).

Figure 29 and Figure 30 visualize the allocation of eight learning stations for the Zürich 1 experiment and the trajectories of the students executing the gamified LBML activity. The eight students started in the upper right corner of the 2D map area (see black rectangle, Figure 29) in four groups of two. The 2D map shows that most students found the learning stations as expected, except for one group in the top area, represented as brown and purple points together with the red station requests. This group was heading north until they turned around and walked to the stations by the lake. This detail cost them at least 20 minutes. One technical issue occurred at station three at the shore of the lake (dark-green station in the bottom picture). The task contained a location-based survey with a mobile app in which students had to map a specific rock type at the rocky shore. But the problem was that the survey application could not be opened, nobody reported this issue to the teachers and, therefore, the students were not able to conduct the mapping task. Figure 30 shows that only two groups, represented as pink and green trajectories, tried to reach station three. The trajectories of individual students generally show that between the two learning stations that are separated by a longer distance, only one of the group members actively used the OMLETH-Player. Both figures show many gaps in the trajectories. This indicates that the students did not use OMLETH regularly. The trajectories revealed that the students moved at a walking speed of 4-5 km/h.

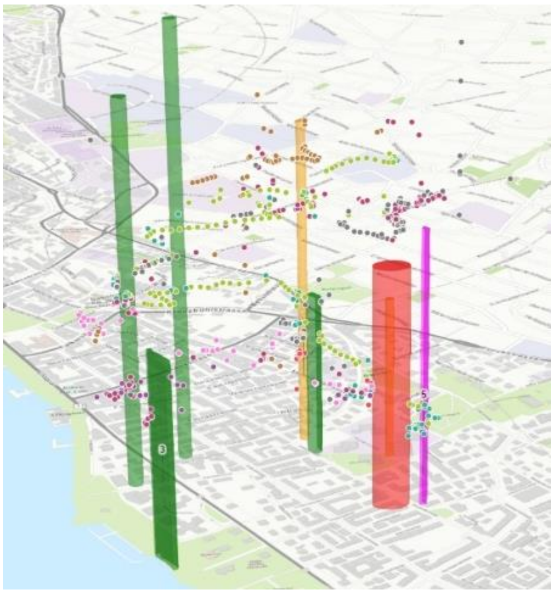


Figure 30 3D map with eight students from Zürich 1 in groups of two executing the experiment, differentiated by color, and visualized as point clouds.

The map includes the learning stations as vertical columns.
(Software: © OMLETH; base map: © Esri).

4.2.2.1.3 Zürich Class 2

Figure 31 visualizes the same allocation of the learning stations as in experiment Zürich 1, but now shows results for experiment Zürich 2. Seven students started the trail again, as indicated in the upper right corner of the 2D map area (see black rectangle, top picture). Initially, the wrong password of OMLETH's geogame trail was communicated. The responsible teacher waiting back in the

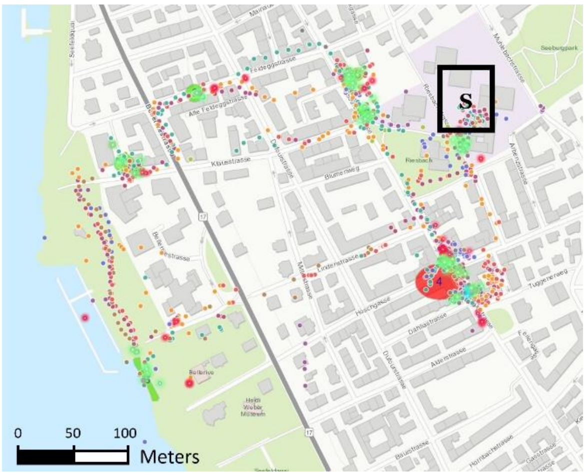


Figure 31 2D map with *seven students of Zürich 2 in three groups executing the experiment, differentiated by color, and visualized as point clouds.*

The map includes the start (black rectangle), the learning stations as circular polygons, and the learning station requests.
(Software: © OMLETH; base map: © Esri

classroom had to search for the password and to come outside. This issue needed some time, thus, the official start encountered a ten-minute delay. The ten students eventually started the self-regulated geogame-trail in four groups and separated in two main directions. The map shows that students were able to spatially orient themselves well in the terrain to find the learning stations. The top picture shows dense point clouds of unresolved requests on the left half of the map at station four.

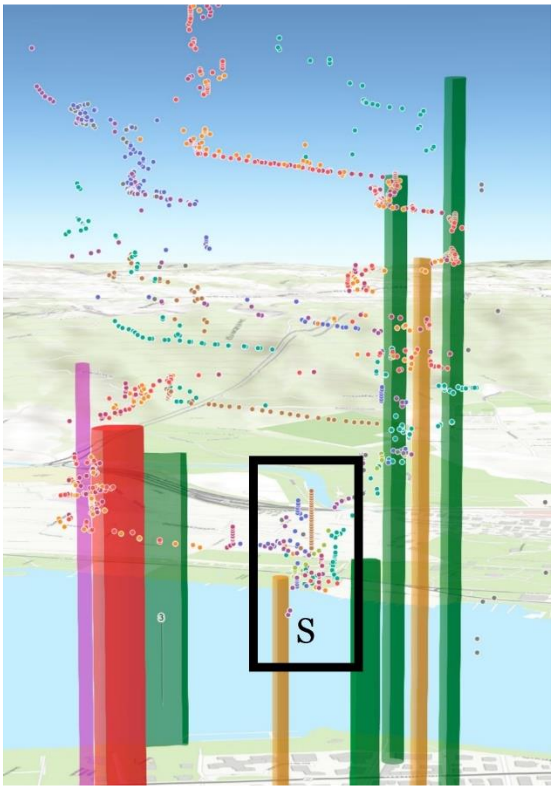


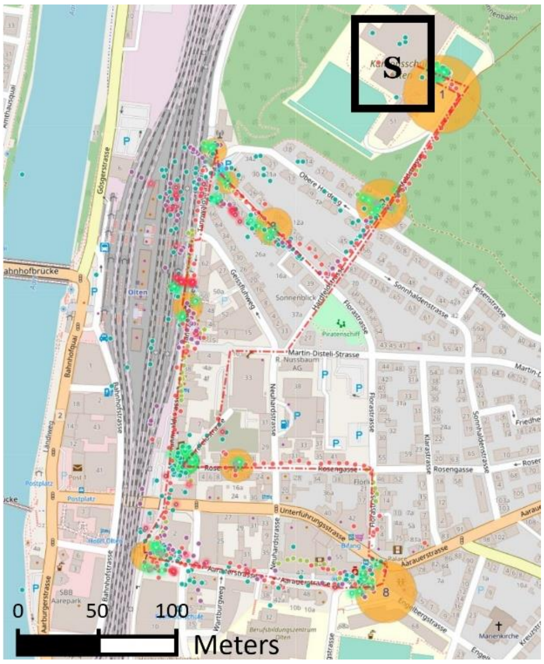
Figure 32 3D map with *seven students of Zürich 2 in three groups executing the experiment, differentiated by color, and visualized as point clouds.*

The map includes the learning stations as vertical columns and the start (black rectangle). (Software: © OMLETH; base map: © Esri).

Figure 32 shows in the start area the different color-separated movement trajectories of the students. The brown trajectory shows with the vertical, linear pattern of extrapolated values for almost 10 minutes due to the complete or partial loss of the satellite signals. As in Section 3.3.1.3.3 described, the issue shows one of the possible uncertainties of positioning with the Geolocation API (including GPS) and how filters try to correct the positions until a fix is available. The map shows that the student was only able to use the OMLETH-Player to its full functionality in the parking area of the lakeshore after about one-third of the entire trail. Furthermore, Figure 32 shows that shortly after launch, clearly sequenced trajectories of related and unrelated students were visible. Two groups (pink/purple and orange/red) remained together and both carried out the mapping inquiry at the learning station three in front of the lake at separate times. It can be assumed that the individual groups did not cooperate much or at least walk with each other, as they were mostly shown as unrelated entities, represented as a vertical gap between the trajectories. The speed value of the trajectories revealed that the students were walking rather slowly, at a speed of 2-4 km/h.

4.2.2.1.4 Olten Class 1

Figure 33 visualizes the allocation of the nine learning stations in Olten's Class 1. Seven students started at the school's main building, shown in the upper area of the 2D map area (see black rectangle, top picture).



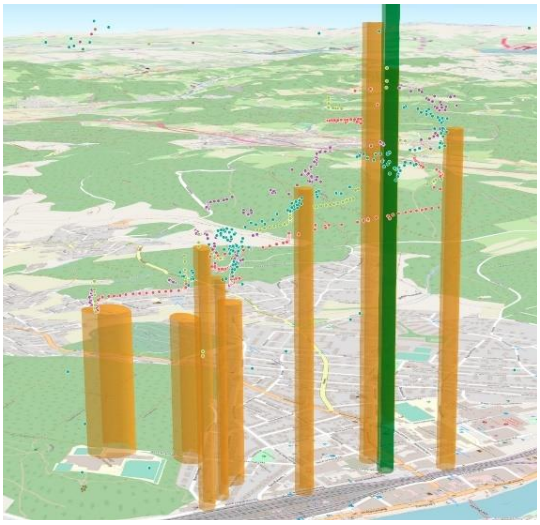


Figure 33 Seven students of Olten 1 in three groups executing the experiment, differentiated by color, and visualized as point clouds.

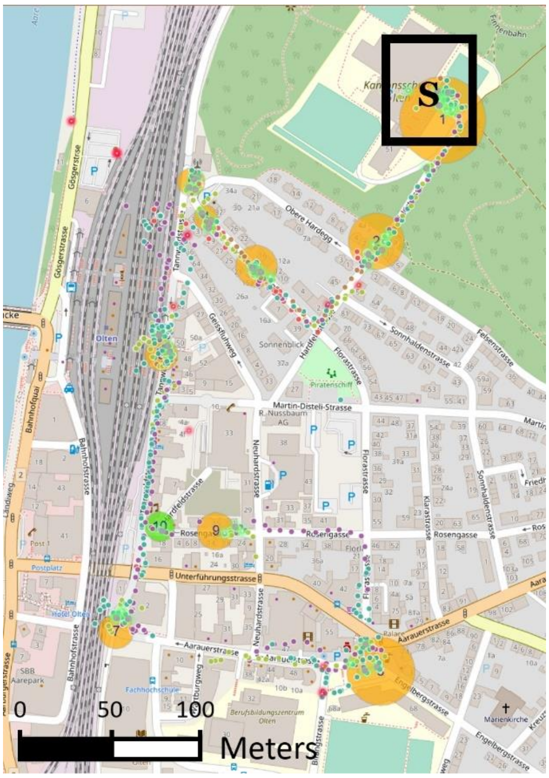
(Top picture) 2D map, including the start (black rectangle), the learning stations as circular polygons, the learning station requests, and the red dashed planned path of the teacher.
(Bottom map) 3D map, including the learning stations as vertical columns.
(Software: © OMLETH; base map: © OSM).

The top picture illustrates that most of the students conducted the trail without issue and could request the learning station. They were able to spatially orient themselves well in the familiar surroundings to find the learning stations.

The 2D map shows two dense point clouds of failed station requests at the railway station. The position accuracies of the corresponding data confirm this issue, which is a typical effect when close to electric-generating infrastructures, such as railway stations. Further away from the railway station, the students were able to access the stations well, as indicated by the light green symbols. The trajectories' time stamps reveal that the students needed significantly more time than anticipated at station seven to evaluate a building project. The bottom picture confirms this observation by the sizeable vertical arrangement of the point clouds. The speed value of the trajectories revealed that the students moved at a walking speed of 4-5 km/h.

4.2.2.1.5 Olten Class 2

Figure 34 visualizes the allocation of the nine learning stations in Olten's class 2. Eight students started at the main building of the school, shown in the upper area of the 2D map area (see black rectangle, top picture).



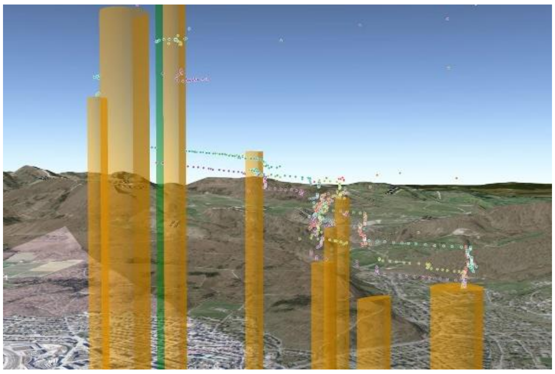


Figure 34 Eight students of Olten 2 in groups of two executing the experiment, differentiated by color, and visualized as point clouds.

(Top picture) 2D map, including the start (black rectangle), the learning stations as circular polygons, and the learning station requests. (Bottom picture) 3D map, including the learning stations as vertical columns. (Software: © OMLETH; base map: © Esri, OSM).

The top picture shows that the students were able to orient themselves well spatially to find the learning stations. Only one pupil used the station request control to navigate between stations 2 and 3.

Trajectory accuracy appears better overall than in the Olten 1 experiment. The railway station map area contains only three failed requests.

The bottom picture shows regular but single trajectories, indicating that the map navigation between two stations was conducted only by one pupil from each group. The gap between the trajectories shows that the groups were separated from each other.

The trajectories show a regular gradient between the stations with a constant but rapid walking speed of 6 - 7 km/h.

In total, the students voluntarily took 10 minutes more time to complete the task and returned to the school after approximately 100 minutes, using their afternoon school recess.

4.2.2.1.6 Aarau

Figure 35 depicts the allocation of the six learning stations in Aarau's second class. Eleven students started in Aarau's old town, shown in the left area of the 2D map (see black rectangle, top picture). The map shows that students were able to spatially orient themselves well in the old town area to find the learning stations.

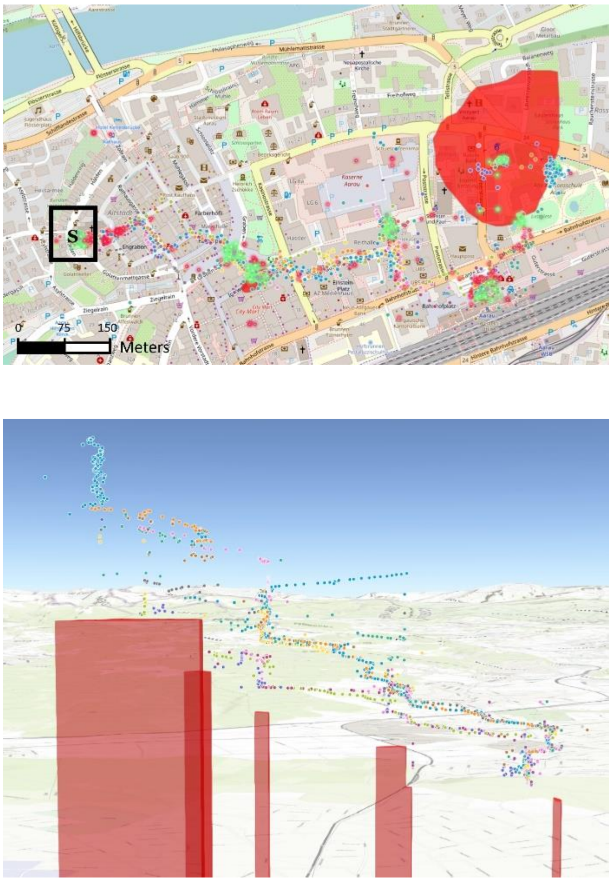


Figure 35 Eleven students of Aarau in five groups executing the experiment, differentiated by color, and visualized as point clouds.

(Top picture) 2D map, including the start (black rectangle), the learning stations as circular polygons, and the learning station requests.
(Bottom picture) 3D map, including the learning stations as vertical columns.
(Software: © OMLETH; basemap: © Esri, OSM).

The same behavior indicated by Olten 2 (see top picture, Figure 34) can be observed in Figure 35 (top picture). Both point to the failed station requests of red points at the beginning of the LBML lesson. Some failed requests also occurred later, but the learning stations show green dense point clouds of successful requests also, indicating that the students could easily access the learning content.

Figure 35 (bottom picture) shows two clusters of trajectories. This indicates that the five groups were mostly not dispersed, but joined together in two main groups to execute the experiment.

The blue point cloud in the top left of the bottom picture and a missing station request indicates that one group did not execute the last station on top of one of the school buildings, but was instead waiting at the entrance to the school for 15 minutes.

4.2.2.2 Results of the technical feedback

This subsection details the technical feedback of OMLETH and the mobile phones' performance during the LBML activities. Figure 36 shows the results, including questions about positioning, web access, and web app performance as bar charts for the experimental group of each class and Table 12 as descriptive statistics.

The students reported on positioning with an overall average score of 4.4 (SD=1.1, MIN=2, MAX=6). Zürich 1 (3.9), Zürich 2 (4.1), and Beromünster (4.1) had the lowest means regarding satisfaction. Two students from Zürich 1 noted that their GPS usage led to flat batteries. Beromünster and Zürich 2 had similar results. Olten 1 and Olten 2 reported satisfactory results in positioning, and Aarau showed the highest mean (5.0).

Figure 36 Technical feedback following the experiments concerning positioning web access and overall performance of OMLETH as bar charts.

Experiments (number of occurrences)	Q1.4 Positioning average score	Q1.5 Web access average score	Q1.6 Performance average score
Beromünster (9)	4.1 (SD=1.1, MIN=2, MAX=5)	4.9 (SD=0.6, MIN=4, MAX=6)	4.7 (SD=0.7, MIN=4, MAX=6)
Zürich 1 (8)	3.9 (SD=1.4, MIN=2, MAX=6)	4.1 (SD=1.1, MIN=2, MAX=5)	4.1 (SD=1.4, MIN=3, MAX=6)
Zürich 2 (7)	4.1 (SD=1.1, MIN=3, MAX=6)	4.0 (SD=0.8, MIN=3, MAX=5)	4.0 (SD=0.8, MIN=3, MAX=5)
Olten 1 (7)	4.4 (SD=1.0, MIN=3, MAX=6)	5.3 (SD=0.8, MIN=4, MAX=6)	4.9 (SD=0.7, MIN=4, MAX=6)
Olten 2 (8)	4.3 (SD=0.9, MIN=3, MAX=5)	4.4 (SD=0.7, MIN=3, MAX=5)	4.5 (SD=1.1, MIN=3, MAX=6)
Aarau (17)	5.0 (SD=0.9, MIN=4, MAX=6)	5.3 (SD=0.7, MIN=4, MAX=6)	4.6 (SD=0.8, MIN=3, MAX=6)
Overall average score	4.4 (SD=1.1, MIN=2, MAX=6)	4.8 (SD=0.9, MIN=3, MAX=6)	4.5 (SD=0.9, MIN=3, MAX=6)

Table 12 Technical feedback following the experiments concerning positioning, web access and overall performance of OMLETH as descriptive statistics.

Web access was evaluated with an overall average score of 4.8 (SD=0.9, MIN=3, MAX=6), with Zürich 2 having the lowest mean (4.0), and Aarau and Olten 1 the highest (5.3). No one gave specific feedback on web access.

The performance of OMLETH received an overall average score of 4.5 (SD=0.9, MIN=3, MAX=6), with Zürich 2 having the lowest mean (4.0), and Olten 1 the highest (4.9). The feedback on Zürich 1 resulted in a significant variance between proponents and opponents. Three students from Aarau reported that OMLETH's usability and design could be improved. One pupil missed the immediate feedback of the assessments, the second was not pleased with the registration, and the third was annoyed by the many tabs in the browser. Aside from that, there were no other qualitative complaints from the 56 students.

4.2.2.3 Findings

The analysis of the environmental context information, the students' movement trajectory analytics, and the results of the qualitative and technical feedback revealed the following findings in the experimental group:

F4.2.1: The context analysis regarding the weather indicated that Zürich 2 and Aarau had a windchill below ten degrees, which several students noted they did not like. In the four other experiments, students did not mention the weather in the open answer question about general comments. Regarding the use of the OMLETH web app, Zürich 2 (23%) and Aarau (33%) showed the lowest rates of the six classes based on Table 10. However, at Beromünster, the learning stations could not be used because it was too cloudy to conduct the radiation exercise to measure the albedo.

F4.2.2: The statistical analysis revealed that Beromünster had a median of 4.2 click requests per pupil and station. This was the highest number of clicks due to a collection of unresolved requests. This finding is also shown as two dense point clouds in Figure 28 (top picture). The most considerable heterogeneity of the "requesters" is demonstrated in Beromünster and Zürich 2, while the students in Olten 2 clicked the station request button a similar amount of times within the group.

F4.2.3: The statistical analysis revealed that the largest experimental group, which was Aarau, with eleven students in five groups, contained the lowest median for station requests, with 1.5 requests per station and pupil. The map-based VA revealed that except for one pupil each in Aarau and Olten 2 at the beginning of the LBML lesson, the students generally understood the purpose and the handling of OMLETH-Player that, for instance, the learning station request button was, although possible, not primarily for orientation and navigation. The speed analytics from the datasets revealed, that the students in Olten 2 generally showed large speed values between the learning stations and more extended stays within the stations. They even spent the school recess to finish the activity.

F4.2.4: The map-based visual analytics confirmed that the passively recorded motion trajectories showed strong accuracy, with a median of between six and twelve meters. This result matched the learning station requests' tolerance of ten meters (blue circle).

F4.2.5: A group from Zürich 1, whose map-based VA suggest a possible orientation problem, reported issues with positioning and consequently showed a reduced motivation to complete the geogame.

F4.2.6: The map-based VA of the Olten 1 LBML lesson revealed that context, such as the railway station electricity, could degrade GPS positioning accuracy and lead to failed requests.

F4.2.7 The technical feedback about the positioning revealed that overall, the students were satisfied with the performance, especially Aarau, with an average score of 5.0. The students from Zürich 1 (3.9), Zürich 2 (4.1), and Beromünster (4.1) reported the lowest means regarding positioning satisfaction.

F4.2.8 The technical feedback about web access showed no particular issues. It revealed that all students encountered satisfactory conditions, in particular, the groups of Aarau (5.3) and Olten 1 (5.3).

F4.2.8 The technical feedback about the overall performance indicated no particular issues regarding the survey. However, three students from Aarau complained about the performance, usability, and design of OMLETH.

F4.2.9 The technical feedback about the overall performance revealed that Aarau (5.0) and Olten 1 (4.9) contained the best results, while Zürich 1 and Zürich 2 showed the lowest feedback with a score of 4.0 in each case.

4.2.3 H4.3 Examination outcome

To investigate whether **H4.3** was supported—that is, whether a location-based mobile learning lesson within a regular classroom teaching session will lead to improved results in examination outcomes—the results of the teacher-guided examinations were obtained.

4.2.3.1 Results of the examinations

The exams were carried out as planned without any particular incidents. The only exception was that in some classes, students were absent from the experimental or control groups. A summary of the examination scores per experiment is depicted in Figure 37 as boxplots, while the descriptive statistics are in Table 13.

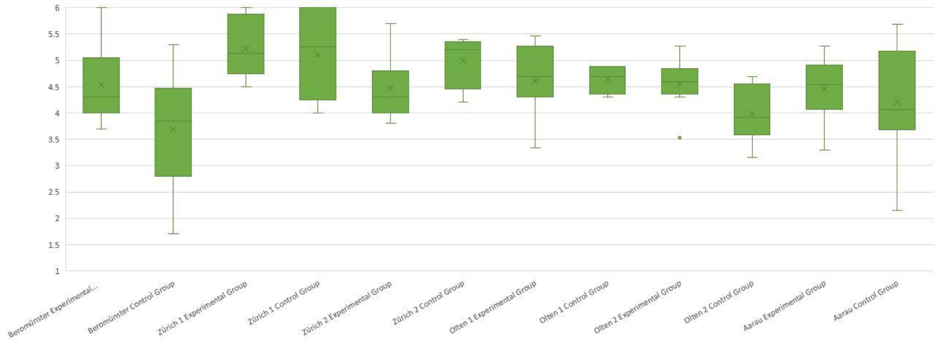


Figure 37 Examination scores for the experimental and control groups of Beromünster, Zürich 1, Zürich 2, Olten 1, Olten 2, and Aarau as box plots.

Classes	Experimental group		Control group		Difference of the means
	n	m (sd, min, max)	n	m (sd, min, max)	
Beromünster	9	4.53 (SD=0.71 MIN=3.70, MAX=6.00)	8	3.68 (SD=1.12, MIN=1.70, MAX=5.50)	0.85
Zürich 1	8	5.22 (SD=0.57, MIN=4.50, MAX=6.00)	7	5.11 (SD=0.92, MIN=4.25, MAX=6.00)	0.11
Zürich 2	7	4.42 (SD=0.63, MIN=3.80, MAX=5.70)	4	5.00 (SD=0.54, MIN=4.20, MAX=5.40)	-0.58
Olten 1	7	4.61 (SD=0.71, MIN=3.25, MAX=5.50)	4	4.56 (SD=0.24, MIN=4.25, MAX=4.75)	0.01
Olten 2	8	4.54 (SD=0.50, MIN=3.50, MAX=5.25)	10	3.98 (SD=0.55, MIN=3.25, MAX=4.50)	0.47
Aarau	17	4.45 (SD=0.54, MIN=3.25, MAX=5.25)	18	4.20 (SD=0.54, MIN=2.25, MAX=5.75)	0.25
Overall average score	56	4.61 (SD=0.63, MIN=3.25, MAX=6.00)	51	4.30 (SD=0.95, MIN=1.70, MAX=6.00)	0.31

Table 13 Examination scores for the experimental group and control group: Number of participants per group, means (m), standard deviation (sd), minimum (min), and maximum (max) of the examination scores for the treatment and control groups of Beromünster, Zürich 1, Zürich 2, Olten 1, Olten 2, and Aarau and the overall score

The grades within the whole sample and within the classes were tested for normality by applying a Kolmogoroff-Smirnov Test at a significance level of $\alpha = .05$. All six experimental groups and control groups can be regarded as normally distributed.

4.2.3.1.1 Comparison between the students

When accounting for a random effect of the classes, teachers, and schools, the linear mixed model revealed for the experimental group, a statistically significant higher average score of 4.61, $t(102.08) = 1.99$, $p = 0.0483$, $d = 0.38$, compared to the control group with 4.30. An ANOVA, computed with the lmertest package, further revealed that none of the random effects school, class, and teacher were significant (all ps > .05). The lowest individual grade occurred at Beromünster, with a score of 1.7 in the control group. Beromünster also achieved the highest grade with a score of 6.0 in the experimental group and both groups of Zürich 1. Outliers were observed in the control group of Olten 2.

4.2.3.1.2 Comparison within the classes

Four of the six classes achieved a higher average score in the experimental group than in the control group. Beromünster's experimental group revealed the most substantial difference to the control group while the experimental group of Zürich 2 showed a substantial negative score to the baseline. However, this statistical power of the difference of Zürich 2 is rather low, since Zürich's 2 control group included only four students. The comparison was tested with a two-sample unpaired t-test, which revealed that the exam scores were never significantly higher for experimental group members than for control group members at $p < .05$. However, the small sample size of the experimental and control groups per class decreased the statistical power and reduced the chance of detecting a statistically significant effect within an individual class.

4.2.3.2 Findings of the examination results

Based on H4.3, the examination score shows evidence of the differences in learning outcomes between classroom teaching and an LBML activity treatment.

F4.3.1: The examination outcome with the analysis of the linear mixed model revealed a statistically significant positive effect of LBML participation. An ANOVA computed that none of the nested groups, such as classes, teachers, and schools, revealed significant influence in the exam results.

F4.3.2: In four of six experimental groups, the average examination grade was higher compared to the control group, where each group had a minimum of seven members. Olten 1 shows an equal average examination grade, but with four students in the control group only. A lower average examination grade for the experimental group did occur in Zürich 2, which contained four students in the control group.

4.2.4 RQ4.4 Self-assessment of the learning outcome

This section reports on the self-assessment of the students of both groups as an alternative to measuring learning outcomes. The results are personal opinions and reveal the situational effects after the experiment of the experimental group in week 5 (see Subsection 4.2.4.1), after the examination of both groups of week 7 (see Subsection 4.2.4.4.2), and both groups of week 16 (see Subsection 4.2.4.4.3). From the educational perspective of school grades, a questionnaire score of ‘slightly agree (4)’ as a reference value was regarded to achieve a positive learning outcome.

4.2.4.1 Experiment survey

This subsection concerns the cognitive self-assessment after the treatment. Figure 38 represents the results as a bar plot, including questions about positioning, web access, and web app performance for the experimental group of each class and Table 14 the corresponding descriptive statistics.

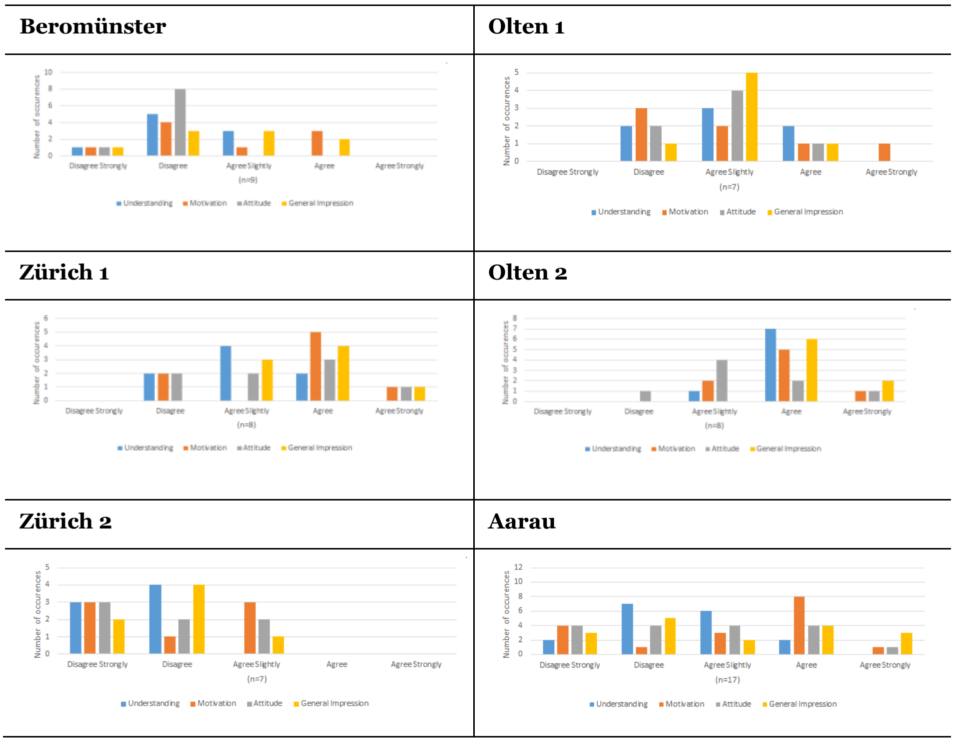


Figure 38 Self-assessment following the experiment about understanding, motivation, attitude, and general impressions of the treatment as descriptive statistics.

Class	Q1.1: Understanding	Q1.2: Motivation	Q1.3: Attitude	Q1.7: General impression
Beromünster	3.2 (SD=0.7, MIN=2, MAX=4)	3.7 (SD=1.1, MIN=2, MAX=5)	2.9 (SD=0.3, MIN=2, MAX=3)	3.7 (SD=1.0, MIN=2, MAX=5)
Zürich 1	4.0 (SD=0.8, MIN=3, MAX=5)	4.6 (SD=1.1, MIN=3, MAX=6)	4.4 (SD=1.1, MIN=3, MAX=6)	4.8 (SD=0.7, MIN=4, MAX=6)
Zürich 2	2.6 (SD=0.5, MIN=2, MAX=3)	3.0 (SD=1.0, MIN=2, MAX=4)	2.9 (SD=0.9, MIN=2, MAX=4)	2.9 (SD=0.7, MIN=2, MAX=4)
Olten 1	4.0 (SD=0.8, MIN=3, MAX=5)	4.0 (SD=1.2, MIN=3, MAX=6)	3.9 (SD=0.7, MIN=3, MAX=5)	4.0 (SD=0.6, MIN=3, MAX=5)
Olten 2	4.9 (SD=0.4, MIN=4, MAX=5)	4.9 (SD=0.6, MIN=4, MAX=6)	4.4 (SD=0.9, MIN=3, MAX=6)	5.3 (SD=0.5, MIN=5, MAX=6)
Aarau	3.5 (SD=0.9, MIN=2, MAX=5)	4.1 (SD=1.3, MIN=2, MAX=6)	3.6 (SD=1.3, MIN=2, MAX=6)	3.9 (SD=1.4, MIN=2, MAX=6)
Overall average score	3.7 (SD=1.0, MIN=2, MAX=5)	4.1 (SD=1.2, MIN=2, MAX=6)	3.7 (SD=1.0, MIN=2, MAX=5)	4.1 (SD=1.2, MIN=2, MAX=6)

Table 14 Self-assessment following the experiment about understanding, motivation, attitude, and general impressions of the treatment as descriptive statistics.

The descriptive statistics are presented with the mean, standard deviation, and minimum and maximum values. A score of 4 is considered as ‘slightly agree’.

- The students reported their understanding with an overall average score of 3.7 (SD=1.0, MIN=2, MAX=5), with Zürich 2 having the lowest mean (2.6), and Olten 2 having the highest (4.9).
- The motivation was evaluated with an overall average score of 4.1 (SD=1.2, MIN=2, MAX=6), with Zürich 2 having the lowest mean (3.0), and Olten 2 having the highest (4.9).
- The attitude was evaluated with an overall average score of 3.7 (SD=1.0, MIN=2, MAX=5), with Zürich 2 having the lowest mean (2.9), and Olten 2 having the highest (5.3).
- The general impression of the experiment received an overall average score of 4.1 (SD=1.2, MIN=2, MAX=6), with Zürich 2 having the lowest mean (2.9), and Olten 2 having the highest (5.3).

By comparing the cognitive learning outcomes, the overall average score shows that affective outcome including attitude (3.7), motivation (4.1), and general impression (4.1) are rated slightly higher than the cognitive outcome with understanding (3.7).

4.2.4.2 Examination survey

The examination survey contained questions about self-assessment of the learning outcome for both groups and opinions and reflection of the LBML lesson for the experimental group again.

4.2.4.2.1 Self-assessment after the examination

This subsection concerns the cognitive self-assessment after the examination. Figure 39 shows the results as bar charts for the individual classes; each row represents a class. The left column represents the data from the experimental group, and the right column, the data from the control group.

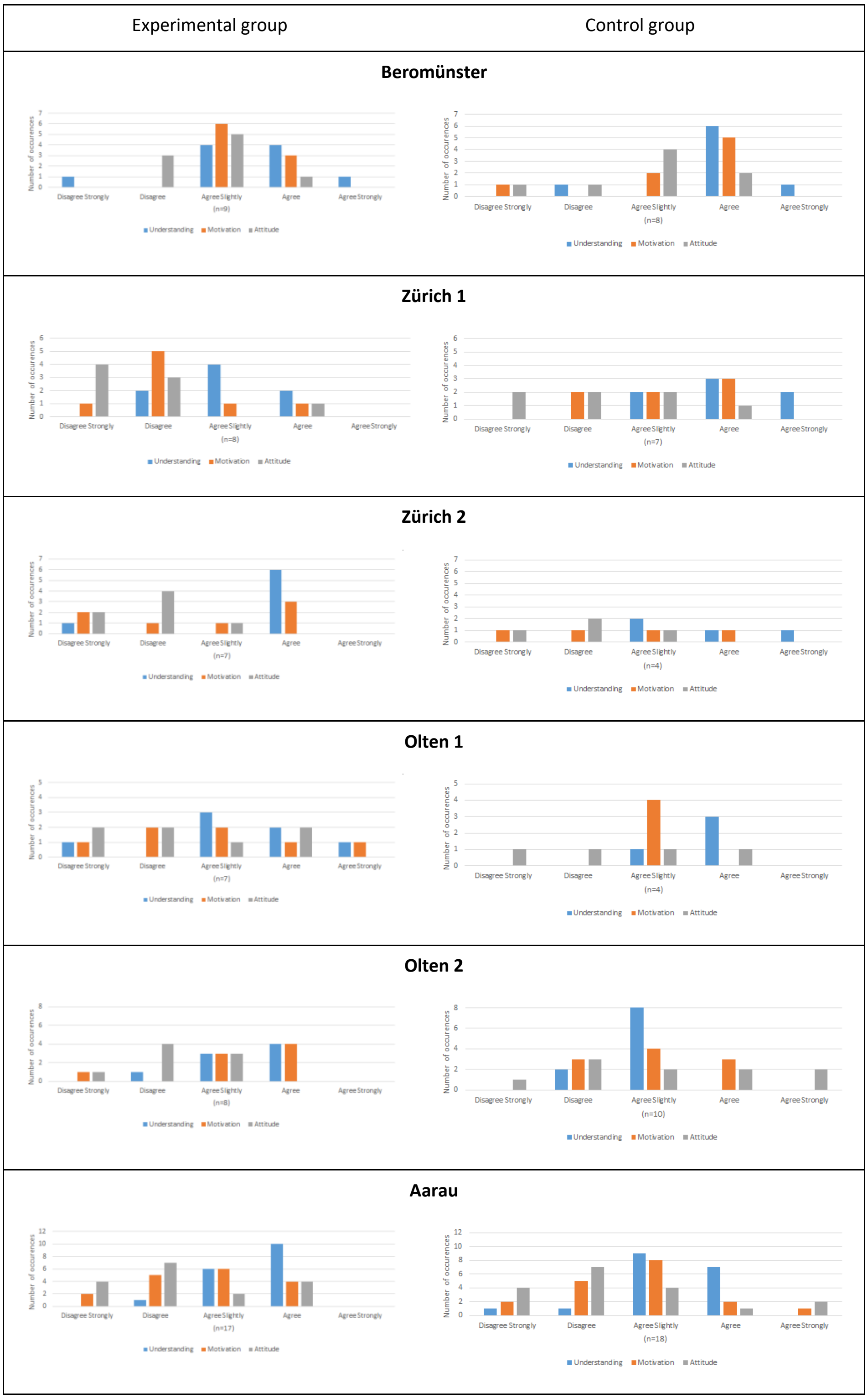


Figure 39 Self-assessment following the examination of understanding, motivation, and attitude of the experimental group (left) and the control group (right).

Table 15 presents the descriptive statistics for the individual classes after the examination, including questions about understanding, motivation, attitude, and general impression (see Table 7).

Experimental group (number of occurrences)	Understanding support	Motivation	Attitude
Beromünster (9)	4.7 (SD=0.7, MIN=4, MAX=6)	4.3 (SD=0.5, MIN=4, MAX=5)	3.8 (SD=0.7, MIN=3, MAX=5)
Zürich 1 (8)	4.0 (SD=0.8, MIN=3, MAX=5)	3.3 (SD=0.9, MIN=2, MAX=5)	2.8 (SD=1.0, MIN=2, MAX=5)
Zürich 2 (7)	4.6 (SD=1.1, MIN=2, MAX=5)	3.7 (SD=1.4, MIN=2, MAX=5)	2.9 (SD=0.7, MIN=2, MAX=4)
Olten 1 (7)	4.3 (SD=1.3, MIN=2, MAX=6)	3.9 (SD=1.3, MIN=2, MAX=6)	3.4 (SD=1.3, MIN=2, MAX=5)
Olten 2 (8)	4.4 (SD=0.7, MIN=3, MAX=5)	4.3 (SD=1.0, MIN=2, MAX=5)	3.3 (SD=0.7, MIN=2, MAX=4)
Aarau (17)	4.5 (SD=0.6, MIN=3, MAX=5)	3.7 (SD=1.0, MIN=2, MAX=5)	3.4 (SD=1.1, MIN=2, MAX=5)
Overall average score	4.4 (SD=0.8, MIN=2, MAX=6)	3.8 (SD=1.0, MIN=2, MAX=6)	3.3 (SD=1.0, MIN=2, MAX=5)

Control group (number of occurrences)	Understanding support	Motivation	Attitude
Beromünster (8)	4.9 (SD=0.8, MIN=3, MAX=6)	4.4 (SD=1.1, MIN=2, MAX=5)	3.9 (SD=1.0, MIN=2, MAX=5)
Zürich 1 (7)	5.0 (SD=0.8, MIN=4, MAX=6)	4.1 (SD=0.9, MIN=3, MAX=5)	3.3 (SD=1.1, MIN=2, MAX=5)
Zürich 2 (4)	4.8 (SD=1.0, MIN=4, MAX=6)	3.5 (SD=1.3, MIN=2, MAX=5)	3.0 (SD=0.8, MIN=2, MAX=4)
Olten 1 (4)	4.8 (SD=0.5, MIN=4, MAX=5)	4.0 (SD=0, MIN=4, MAX=4)	3.5 (SD=1.3, MIN=2, MAX=5)
Olten 2 (10)	3.8 (SD=0.4, MIN=3, MAX=4)	4.0 (SD=0.8, MIN=3, MAX=5)	4.1 (SD=1.4, MIN=2, MAX=6)
Aarau (18)	4.2 (SD=0.8, MIN=2, MAX=5)	3.7 (SD=1, MIN=2, MAX=6)	3.4 (SD=1.2, MIN=2, MAX=6)
Overall average score	4.4 (SD=0.8, MIN=2, MAX=6)	3.9 (SD=1.0, MIN=2, MAX=6)	3.6 (SD=1.2, MIN=2, MAX=6)

Table 15 Self-assessment following the examination of the experimental group (upper row) and the control group (lower row).

The students in the experimental group reported as follows:

- Understanding was assessed with an overall average score of 4.4 (SD=0.8, MIN=2, MAX=6), with Zürich 1 having the lowest mean (4.0), and Beromünster having the highest (4.7).
- Motivation was evaluated with an overall average score of 3.8 (SD=1.0, MIN=2, MAX=6), with Zürich 1 having the lowest mean (3.3), and Beromünster and Olten 2 both having the highest (4.3).
- Attitude was evaluated with an overall average score of 3.3 (SD=1.0, MIN=2, MAX=5), with Zürich 1 having the lowest mean (2.8), and Beromünster having the highest (3.8).

The students in the control group provided self-assessment ratings as well and reported as follows:

- Understanding was evaluated with an overall average score of 4.4 (SD=0.8, MIN=2, MAX=6), with Olten 1 having the lowest mean (3.8), and Zürich 1 having the highest (5.0).
- Motivation was evaluated with an overall average score of 3.9 (SD=1.0, MIN=2, MAX=6), with Aarau having the lowest mean (3.7), and Beromünster having the highest (4.4).
- Attitude was evaluated with an overall average score of 3.6 (SD=1.2, MIN=2, MAX=6), with Zürich 2 having the lowest mean (3.0), and Olten 2 having the highest (4.1).

4.2.4.2.2 Reported view and reflections

This subsection concerns the personal views and reflections of the experiment by the members of the experimental group after the examination (see Table 7). It addresses their satisfaction with the LBML experience (Q2.1), their evaluation of LBML as an educational approach (Q2.2), and their feedback on the novelty factor (Q2.3). Further reflection was requested regarding the personal added value of the treatment as it pertained to preparation for the examination.

Experiments (number of occurrences)	Q2.1 Trail enjoyment	Q2.2 Mobile learning	Q2.3 Innovative approach
Beromünster (9)	4.1 (SD=1.1, MIN=3, MAX=6)	4.2 (SD=0.8, MIN=3, MAX=5)	4.8 (SD=1, MIN=3, MAX=6)
Zürich 1 (8)	4.3 (SD=0.7, MIN=3, MAX=5)	4.1 (SD=1.4, MIN=2, MAX=6)	4.4 (SD=0.7, MIN=3, MAX=5)
Zürich 2 (7)	2.9 (SD=0.4, MIN=2, MAX=3)	3.3 (SD=1.1, MIN=2, MAX=5)	3.0 (SD=0.6, MIN=2, MAX=4)
Olten 1 (7)	4.1 (SD=1.2, MIN=3, MAX=6)	3.9 (SD=1.2, MIN=3, MAX=6)	4.3 (SD=0.8, MIN=3, MAX=5)
Olten 2 (8)	5.0 (SD=0.5, MIN=4, MAX=6)	4.6 (SD=0.5, MIN=4, MAX=5)	5.3 (SD=0.7, MIN=4, MAX=6)
Aarau (17)	4.0 (SD=1.2, MIN=2, MAX=6)	3.8 (SD=1.1, MIN=2, MAX=5)	4.1 (SD=1.2, MIN=2, MAX=6)
Overall average score	4.1 (SD=1.1, MIN=2, MAX=6)	4.0 (SD=1.1, MIN=2, MAX=6),	4.3 (SD=1.1, MIN=2, MAX=6),

Table 16 Reflections of the experimental groups following the examination regarding the pedagogical value of the LBML activity.

Table 16 presents the descriptive statistics for the experimental groups regarding the pedagogical value of the LBML after the examination.

- The first question asked whether the pupil enjoyed the module. This question was answered with an overall average score of 4.1 (SD=1.1, MIN=2, MAX=6), with Zürich 2 having the lowest mean (2.9), and Olten 2 having the highest (5.0).
- The second question concerned mobile learning on mobile phones. This question was answered with an overall average score of 4.0 (SD=1.1, MIN=2, MAX=6), with Zürich 2 having the lowest mean (3.3), and Olten 2 having the highest (4.6).
- The third question was about assessing the opinion of whether the LBML was thought to be innovative. This question was answered with an overall average score of 4.3 (SD=1.1, MIN=2, MAX=6), with Zürich 2 having the lowest mean (3.0), and Olten 2 having the highest (5.3).

The three questions highlight the strong consistency of Zürich 2 low / Olten 2 high across the board.

Experiments (number of occurrences)	Q2.5 Cognitive value for examination	Q2.6 Motivational value for examination
Beromünster (9)	3.6 (SD=0.7, MIN=3, MAX=5)	3 (SD=1.1, MIN=2, MAX=5)
Zürich 1 (8)	3.4 (SD=0.7, MIN=2, MAX=4)	3.1 (SD=0.6, MIN=2, MAX=4)
Zürich 2 (7)	2.4 (SD=0.8, MIN=2, MAX=4)	2.9 (SD=0.9, MIN=2, MAX=4)
Olten 1 (7)	3.6 (SD=1.0, MIN=2, MAX=5)	3.4 (SD=1.3, MIN=2, MAX=5)
Olten 2 (8)	4.1 (SD=0.6, MIN=3, MAX=5)	4.0 (SD=0.9, MIN=3, MAX=5)
Aarau (17)	3.2 (SD=1.0, MIN=2, MAX=5)	2.7 (SD=0.8, MIN=2, MAX=5)
Overall average score	3.4 (SD=0.9, MIN=2, MAX=5)	3.1 (SD=1.0, MIN=2, MAX=5)

Table 17 Reflections of the experimental groups following the examination concerning the cognitive and motivational value of LBML for the classroom examination.

Table 17 depicts the descriptive statistics of the experimental groups for the cognitive and motivational value of the LBML after the examination.

- The cognitive value responses had an overall average score of 3.4 (SD=0.9, MIN=2, MAX=5), with Zürich 2 having the lowest mean (2.4), and Olten 2 having the highest (4.1).
- The increase in the motivation to learn for the examination was reported with an overall average score of 3.1 (SD=1.0, MIN=2, MAX=5), with Aarau having the lowest mean (2.7), and Olten 2 having the highest (4.0).

4.2.4.3 Long-term survey

The long-term survey contained questions about the self-assessment of learning outcomes for both groups, plus a review of the trail for the experimental group.

4.2.4.3.1 Self-assessment

This subsection concerns the cognitive self-assessment at the time of the long-term observation three months after the exam. Figure 40 shows bar charts for the individual classes, and each row represents a class. The left columns represent the data from the experimental group and the right columns the data from the control group.

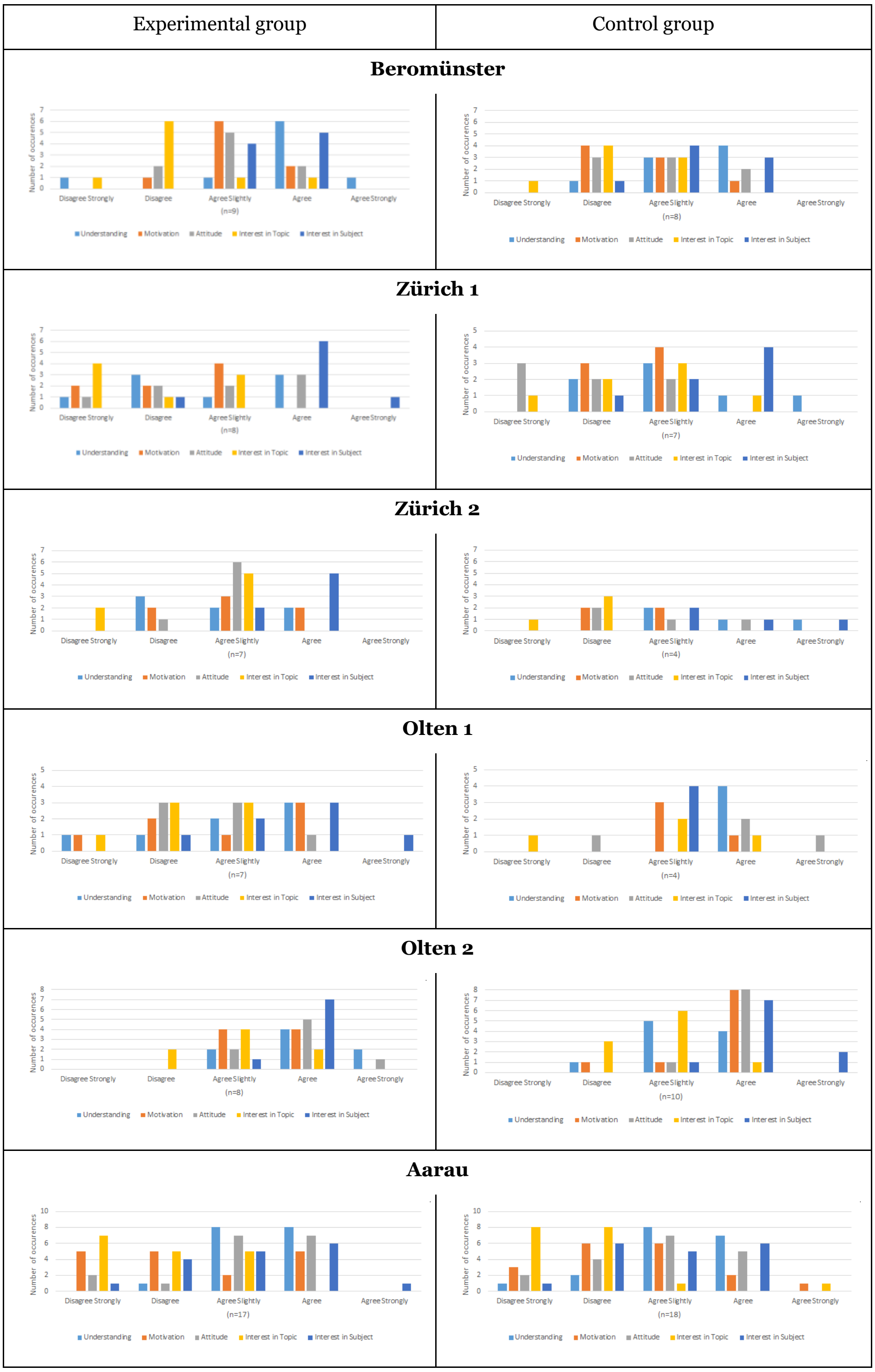


Figure 40 Self-assessment of the long-term observation regarding understanding, motivation, and attitude, plus the general interest in the topic and subject, of (left) the experimental group (left) and (right) the control group.

Table 18 presents the descriptive statistics of the individual classes at the time of the long-term observation for the self-assessments in understanding (Q3.6), motivation (Q3.7), and attitude (Q3.8):

Experimental group (number of occurrences)	Q3.6 Understanding	Q3.7 Motivation	Q3.8 Attitude
Beromünster (9)	4.7 (SD=1.1, MIN=2, MAX=6)	4.1 (SD=0.6, MIN=3, MAX=5)	3.2 (SD=0.8, MIN=2, MAX=5)
Zürich 1 (8)	3.8 (SD=1.2, MIN=2, MAX=5)	3.3 (SD=0.9, MIN=2, MAX=4)	2.9 (SD=1.0, MIN=2, MAX=4)
Zürich 2 (7)	3.9 (SD=0.9, MIN=3, MAX=5)	4.0 (SD=0.8, MIN=3, MAX=5)	3.4 (SD=1.0, MIN=2, MAX=4)
Olten 1 (7)	4.0 (SD=1.2, MIN=2, MAX=5)	3.9 (SD=1.2, MIN=2, MAX=5)	3.3 (SD=0.8, MIN=2, MAX=4)
Olten 2 (8)	5.0 (SD=0.8, MIN=4, MAX=6)	4.5 (SD=0.5, MIN=4, MAX=5)	4.0 (SD=0.8, MIN=3, MAX=5)
Aarau (17)	4.4 (SD=0.6, MIN=3, MAX=5)	3.4 (SD=1.2, MIN=2, MAX=5)	2.9 (SD=0.9, MIN=2, MAX=4)
Overall average score	4.3 (SD=0.9, MIN=2, MAX=6)	3.8 (SD=1.0, MIN=2, MAX=5)	3.2 (SD=0.9, MIN=2, MAX=5)

Control group (number of occurrences)	Q3.6 Understanding	Q3.7 Motivation	Q3.8 Attitude
Beromünster (8)	4.4 (SD=0.7, MIN=3, MAX=5)	3.6 (SD=0.7, MIN=3, MAX=5)	3.3 (SD=0.7, MIN=2, MAX=4)
Zürich 1 (7)	4.1 (SD=1.1, MIN=3, MAX=6)	3.6 (SD=0.5, MIN=3, MAX=4)	2.9 (SD=0.9, MIN=2, MAX=4)
Zürich 2 (4)	4.8 (SD=1.0, MIN=4, MAX=6)	3.5 (SD=0.6, MIN=3, MAX=4)	2.8 (SD=0.5, MIN=2, MAX=3)
Olten 1 (4)	5.0 (SD=0.0, MIN=5, MAX=5)	4.3 (SD=0.5, MIN=4, MAX=5)	3.8 (SD=1.3, MIN=2, MAX=5)
Olten 2 (10)	4.3 (SD=0.7, MIN=3, MAX=5)	4.7 (SD=0.7, MIN=3, MAX=5)	3.8 (SD=0.6, MIN=3, MAX=5)
Aarau (18)	4.2 (SD=0.9, MIN=2, MAX=5)	3.6 (SD=1.1, MIN=2, MAX=6)	2.8 (SD=1.0, MIN=2, MAX=6)
Overall average score	4.3 (SD=0.8, MIN=2, MAX=6)	3.8 (SD=0.9, MIN=2, MAX=5)	3.2 (SD=0.9, MIN=2, MAX=5)

Table 18 Self-assessment of the long-term observation of the experimental group (upper row) and the control group (lower row).

- The students in the experimental group reported their understanding with an overall average score of 4.3 (SD=0.9, MIN=2, MAX=6), with Zürich 1 having the lowest mean (3.8), and Olten 2 having the highest (5). The students in the control group reported their understanding with an overall average score of 4.3 (SD=0.8, MIN=2, MAX=6), with Zürich 1 having the lowest mean (4.1), and Olten 1 having the highest (5).
- Motivation in the experimental group was evaluated with an overall average score of 3.8 (SD=1.0, MIN=2, MAX=5), with Zürich 1 having the lowest mean (3.3), and Olten 2 having the highest (4.5). Motivation in the control group was evaluated with an overall average score of 3.8 (SD=0.9, MIN=2, MAX=5), with Zürich 2 having the lowest mean (3.5), and Olten 2 having the highest (4.7).
- Attitude in the experimental group was rated with an overall average score of 3.2 (SD=0.9, MIN=2, MAX=5), with Zürich 1 and Aarau having the lowest mean (2.9), and Olten 2 having the highest (4.0).

Attitude in the control group was evaluated with an overall average score of 3.2 (SD=0.9, MIN=2, MAX=5), with Zürich 2 and Aarau having the lowest mean (2.8), and Olten 1 and Olten 2 having the highest (3.8).

At the time of the long-term observation, both learning outcomes, the cognitive outcome with understanding and the affective outcome with motivation and attitude, were self-assessed by both groups approximately even. The students reported understanding as sufficient (4.3), while motivation (3.8) and attitude (3.2) were evaluated below the targeted value of 4. The understanding decreased by 0.1 compared to the survey after the examination, and the motivation of the control group also decreased by 0.1 compared to the survey after the examination. The attitude result for the experimental group compared with the control group was not significantly better, $t(105) = 0.43$, $p = .66$, at $p < 0.05$.

Table 19 presents the descriptive statistics of the individual classes at the time of the long-term observation. The statistics include two reflective questions regarding interest in the topic (Q3.2) and subject (Q3.1), which were asked before the teaching sequence took place as a baseline to measure potential influences on the results.

Experimental group (number of occurrences)	Q3.2 Interest in the topic	Q3.1 Interest in the subject
Beromünster (9)	4.0 (SD=0.7, MIN=3, MAX=5)	4.6 (SD=0.5, MIN=4, MAX=5)
Zürich 1 (8)	3.9 (SD=1.1, MIN=2, MAX=5)	4.9 (SD=0.8, MIN=3, MAX=6)
Zürich 2 (7)	3.9 (SD=0.4, MIN=3, MAX=4)	4.7 (SD=0.5, MIN=4, MAX=5)
Olten 1 (7)	3.7 (SD=0.8, MIN=3, MAX=5)	4.6 (SD=1, MIN=3, MAX=6)
Olten 2 (8)	4.9 (SD=0.6, MIN=4, MAX=6)	4.9 (SD=0.4, MIN=4, MAX=5)
Aarau (17)	4.1 (SD=1.0, MIN=2, MAX=5)	4.1 (SD=1.1, MIN=2, MAX=6)
Overall average score	4.1 (SD=0.9, MIN=2, MAX=6)	4.5 (SD=0.8, MIN=2, MAX=6)

Control group (number of occurrences)	Q3.2 Interest in the topic	Q3.1 Interest in the subject
Beromünster (8)	3.9 (SD=0.8, MIN=3, MAX=5)	4.3 (SD=0.7, MIN=3, MAX=5)
Zürich 1 (7)	3.6 (SD=1.0, MIN=2, MAX=5)	4.4 (SD=0.8, MIN=3, MAX=5)
Zürich 2 (4)	3.8 (SD=1.0, MIN=3, MAX=5)	4.8 (SD=1.0, MIN=4, MAX=6)
Olten 1 (4)	4.8 (SD=1.3, MIN=3, MAX=6)	4.0 (SD=0.0, MIN=4, MAX=4)
Olten 2 (10)	4.9 (SD=0.3, MIN=4, MAX=5)	5.1 (SD=0.6, MIN=4, MAX=6)
Aarau (18)	3.8 (SD=1.0, MIN=2, MAX=5)	3.9 (SD=1.0, MIN=2, MAX=5)
Overall average score	4.1 (SD=1.0, MIN=2, MAX=6)	4.3 (SD=0.9, MIN=2, MAX=6)

Table 19 General interest in the topic and subject amongst the experimental group (upper row) and control group (lower row) at the time of the long-term observation.

The results for the baseline questions regarding initial attitude or interest in the topic and the subject are as follows:

- The students in the experimental group reported their interest in the specific topic before the teaching unit started, with an overall average score of 4.1 (SD=0.9, MIN=2, MAX=6). Olten 1 had the lowest mean (2.9), and Olten 2 had the highest (4.0). Interest in the specific topic in the control group was evaluated with an overall average score of 4.1 (SD=1.0, MIN=2, MAX=6), with Zürich 1 having the lowest mean (3.6), and Olten 2 having the highest (4.9).
- The students in the experimental group reported their attitude and interest toward Geography with an overall average score of 4.5 (SD=0.8, MIN=2, MAX=6), with Aarau having the lowest mean

(4.1), and Zürich 1 and Olten 2 having the highest (4.9). Attitude and interest toward Geography in the control group were evaluated with an overall average score of 4.3 (SD=0.9, MIN=2, MAX=6), with Aarau having the lowest mean (3.9), and Olten 2 having the highest (5.1).

Comparing the groups illustrates that the interest in the specific topic was rated equally by both groups. Attitude and interest toward Geography amongst the experimental group compared with the control group was rated slightly better with a score of 0.2, but not statistically significant, $t(105) = -1.22$, $p = .22$, at $p < 0.05$.

4.2.4.3.2 Reported views and reflections

This subsection concerns the personal views and reflections of the experiment by students of the experimental group in the long-term. It addresses their desire to learn about a new topic in a situated setting with their mobile phones (Q3.4). It also discusses how the students would behave had the exam been executed as an LBML module, such as actively exploring for similar examples (Q3.51) or repeating the existing LBML module (Q3.52).

Table 20 presents the descriptive statistics for the individual experimental groups. The willingness (Q3.4) to elaborate on a topic once again with location-based examples and the personal mobile phone got an agreement of an overall average score of 3.9 (SD=1.4, MIN=2, MAX=6), with Zürich 1 having the lowest mean (3.3), and Olten 2 having the highest (5.3). To the question (Q3.51) if the student would actively explore similar examples in everyday life, if the examination were also designed as such a module, the students show an agreement with an overall average score of 3.6 (SD=1.0, MIN=2, MAX=5), with Zürich 1 having the lowest mean (2.9), and Olten 2 having the highest (4.4).

Experimental group (number of occurrences)	**Q3.4 Repeat an LBML activity**	**Q3.51 Inquiry for examination**	**Q3.52 Repeat for examination**
Beromünster (9)	3.7 (SD=1.4, MIN=2, MAX=5)	3.9 (SD=0.9, MIN=3, MAX=5)	4.2 (SD=1.2, MIN=2, MAX=6)
Zürich 1 (8)	3.3 (SD=1.2, MIN=2, MAX=5)	2.9 (SD=1.1, MIN=2, MAX=5)	3.4 (SD=1.3, MIN=2, MAX=5)
Zürich 2 (7)	3.6 (SD=1.4, MIN=2, MAX=6)	3.6 (SD=1, MIN=2, MAX=5)	3.7 (SD=1.1, MIN=2, MAX=5)
Olten 1 (7)	4.1 (SD=1.3, MIN=3, MAX=6)	3.3 (SD=1.3, MIN=2, MAX=5)	3.6 (SD=1.7, MIN=2, MAX=6)
Olten 2 (8)	5.3 (SD=0.7, MIN=4, MAX=6)	4.4 (SD=0.5, MIN=4, MAX=5)	5.0 (SD=0.8, MIN=4, MAX=6)
Aarau (17)	3.8 (SD=1.4, MIN=2, MAX=6)	3.6 (SD=1.1, MIN=2, MAX=5)	3.9 (SD=1.2, MIN=2, MAX=6)
Overall average score	3.9 (SD=1.4, MIN=2, MAX=6)	3.6 (SD=1.0, MIN=2, MAX=5)	4.0 (SD=1.3, MIN=2, MAX=6)

Table 20 Assessment reflections of the experimental group after the long-term observation concerning the examination preparation.

If the learning content were to be assessed as an LBML activity (Q3.52), the students agreed to repeat the existing module with an overall average score of 4.0 (SD=1.3, MIN=2, MAX=6). Zürich 1 had the lowest mean (3.4), and Olten 2 had the highest (5.0). Three Aarau students used the term efficiency as a reason for considering the methodology as unsuitable, believing that much less exam-relevant content can be acquired in the double lesson of an LBML activity than with the traditional materials in the classroom or at home.

4.2.4.4 Findings

Based on the results, the following key findings regarding the surveys' self-assessment questions were derived:

4.2.4.4.1 Experiment survey

F4.4.1: After the experiment, the experimental group rated both understanding and attitude with a mean of 3.7, lower than motivation (4.1) and general impressions (4.1).

F4.4.2: The treatment survey results indicated that Zürich 2 consistently showed the lowest ratings concerning self-assessment and general impression, and Olten 2 students self-assessed their learning progress as the best.

4.2.4.4.2 Examination survey

F4.4.3: The understanding after the examination was scored 4.4 each in the experimental group as well as in the control group. Compared with the control group, and in the context of the two-sample unpaired t-test, motivation amongst the experimental group with 0.1 score difference was not significantly worse, $t(105) = -0.53$, $p = .30$, at $p < 0.05$, as was attitude with 0.3 score difference, $t(105) = -1.53$, $p = .06$, at $p < 0.05$. Concerning the experimental group, the changes from the experimental questionnaire to the examination questionnaire revealed at $p<.01$ a statistically significant increase of understanding from 3.7 to 4.4 ($F(1,110) = 19.3$, $p=0.000051$), a not significant decrease of motivation from 4.1 to 3.8 ($F(1,110) = 1.5$, $p=0.21$), and a not significant decrease of attitude from 3.7 to 3.3 ($F(1,110) = 5.1$, $p=0.02$), based on a one-way ANOVA.

F4.4.4: Regarding LBML as the teaching strategy, the Olten 2 students assessed the LBML experience as well as the educational approach of LBML as very positive. The Zürich 2 students rated the experience and the pedagogical value of the approach as entirely negative.

F4.4.5: Regarding the impact of the summative assessment, only the Olten 2 students agreed to a reasonably positive cognitive and motivational effect of the outdoor experience on learning for the examination. Students at all other schools evaluated the experience as having no impact. Not a single student strongly agreed with both statements of positive cognitive and motivational effects.

4.2.4.4.3 Long-term survey

F4.4.6: In the long-term, the self-assessed understanding (4.3), motivation (3.8), between the experimental group and control group were, on average, reported as equivalent, and the self-assessed attitude at $p<.05$ a not significant decrease (3.1, $F(1,110) = 0.08$, $p=0.76$), based on a one-way ANOVA.

F4.4.7 In the long-term survey, it was reported that on average the general interest in Geography, as a subject, was indicated with an average score of 4.5 slightly stronger in the experimental group with a difference of 0.2 to the control group, while the interest in the topic before the teaching unit took place was reported with an average score of 4.1 for both groups as rather moderate.

F4.4.8 The desire to carry out a topic other than LBML activity and the personal mobile phone was confirmed with an average score of 3.9 and a large heterogeneity (SD=1.4). In the case of an examination as an LBML module, the average students would repeat an existing LBML module as exam preparation with a low agreement of 4.0, but would not actively explore for similar examples from everyday life (average score of 3.6).

4.2.5 RQ4.5 Memories and benefits of the LBML lesson

The examination survey contained questions about the ability to list the content of all the learning stations completed during the LBML trail. Results regarding the cognitive benefits and ability to link the content to future discoveries are presented in Subsection 4.2.5.1, and the findings are in Subsection 4.2.5.2.

4.2.5.1 LBML lesson memories after the examination and in the long-term

This subsection reports the results of LBML activity memory retention, focusing on the self-reported ability to explain the content of all the learning stations after the examination, and in the long-term.

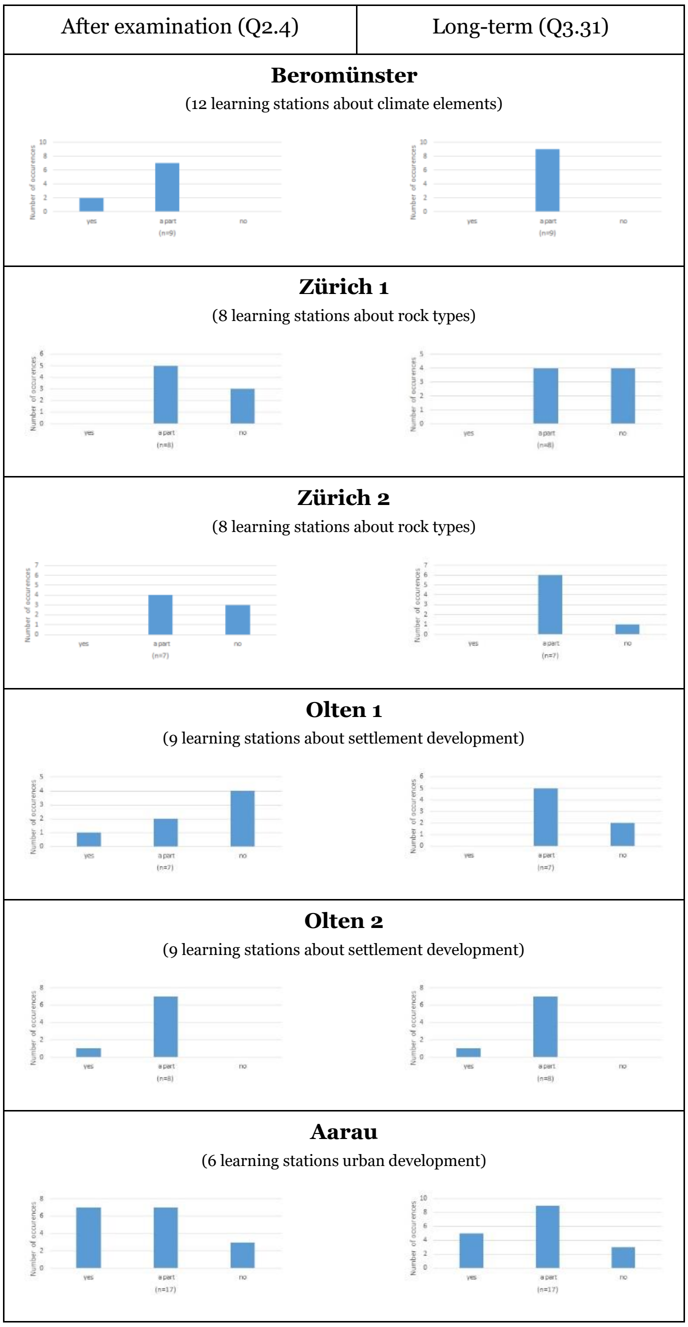


Figure 41 LBML activity memories following the examination (left) and in the long-term (right) of the students by class.

Figure 41 shows bar charts of the results of the ability to recall LBML lesson content (learning station topic) of the experimental group, where each row represents an individual class, including the metainformation about the number of learning stations and the learning subject. The results of the self-assessment statement on the ability to explain the content of all learning stations completed along the trail are shown in the left column with the results of Q2.4 after the examination and in the right column with the results of Q3.31 at the time of the long-term observation. The question was of the multiple-choice type with the possible choices, yes, a part, no.

The charts show that after the examination (approximately two weeks after the trail), a part of students of each classes assessed to be able to explain a part of the content of the learning stations. Especially in Aarau, 7 of the 17 students estimated that they can explain the learning stations again. At the time of the long-term observation (three months after the trail), the majority of students of each classes noted that they could explain a part of the content of the learning stations. The charts show that students from Aarau with six learning stations about urban development, and Olten 2 with nine learning stations about settlement development, considered themselves able to list and explain all the topics of the LBML lesson in the long-term.

Experimental group (number of occurrences)	**Number of learning stations**	**Q2.4 Trail memories score after examination** (1= nothing; 2= a part of, 3=everything)	**Q3.31 Trail memories score in the long-term** (1= nothing; 2= a part of, 3=everything)
Beromünster (9)	12	2.2 (SD=0.4, MIN=2, MAX=3)	2 (SD=0, MIN=2, MAX=2)
Zürich 1 (8)	8	1.6 (SD=0.5, MIN=1, MAX=2)	1.5 (SD=0.5, MIN=1, MAX=2)
Zürich 2 (7)	8	1.6 (SD=0.5, MIN=1, MAX=2)	1.9 (SD=0.4, MIN=1, MAX=2)
Olten 1 (7)	9	1.6 (SD=0.8, MIN=1, MAX=3)	1.7 (SD=0.5, MIN=1, MAX=2)
Olten 2 (8)	9	2.1 (SD=0.4, MIN=2, MAX=3)	2.1 (SD=0.4, MIN=2, MAX=3)
Aarau (17)	6	2.2 (SD=0.8, MIN=1, MAX=3)	2.1 (SD=0.7, MIN=1, MAX=3)
Overall average score		2.0 (SD=0.7, MIN=1, MAX=3)	1.9 (SD=0.5, MIN=1, MAX=3)

Table 21 LBML lesson memories following the examination (left) and in the long-term (right) by class (background color of the statistics: green=highest mean; red=lowest mean).

Table 21 presents the descriptive statistics about the memories of the trail for the experimental group and includes the number of learning stations. The left column shows the results after the examination, and the right column the results at the time of the long-term observation. The students reported an overall average score of 2.0 (SD=0.7, MIN=1, MAX=3) after the examination, which fits the assessment of “a part”. Zürich 1, Zürich 2, and Olten 1 had the lowest mean (1.6), and Beromünster and Aarau had the highest (2.2). In the long-term observation, the students reported an overall average score of 1.9 (SD=0.5, MIN=1, MAX=3), with Zürich 1 having the lowest mean (1.5), and Beromünster and Aarau having the highest (2.1).

4.2.5.2 Cognitive benefit and the situational memories in the long-term

This subsection concerns the results of the self-assessed cognitive benefit of the experience and the situational memories when the learning content is encountered in a new context.

Table 22 presents the descriptive statistics concerning whether the trail experiences would benefit the pupil's knowledge on the topic (left column) and whether students were able to remember the LBML lesson's content by applying the knowledge or skills to new examples (right column).

Experimental group (number of occurrences)	**Q3.32 The cognitive benefit of the experience in the long-term**	**Q3.33 Situational memories in the long-term**
Beromünster (9)	3.6 (SD=1.1, MIN=2, MAX=6)	4.6 (SD=0.7, MIN=3, MAX=5)
Zürich 1 (8)	3.3 (SD=0.9, MIN=2, MAX=5)	3.0 (SD=1.1, MIN=2, MAX=5)
Zürich 2 (7)	3.3 (SD=0.8, MIN=2, MAX=4)	3.0 (SD=0.8, MIN=2, MAX=4)
Olten 1 (7)	3.4 (SD=1.1, MIN=2, MAX=5)	4.0 (SD=0.8, MIN=3, MAX=5)
Olten 2 (8)	4.4 (SD=0.9, MIN=3, MAX=6)	5.1 (SD=0.6, MIN=4, MAX=6)
Aarau (17)	3.5 (SD=1, MIN=2, MAX=5)	3.7 (SD=1.3, MIN=2, MAX=6)
Overall average score	3.6 (SD=1.0, MIN=2, MAX=6)	3.9 (SD=1.4, MIN=2, MAX=2)

Table 22 Situational benefits for the current expertise and situational memories in the long-term observation.

The cognitive benefit of the experience received an overall average score of 3.6 (SD=1.0, MIN=2, MAX=6). Zürich 1 and Zürich 2 (rock types) had the lowest mean (3.3), and Olten 2 (settlement development) had the highest (4.4). The students reported on their situational memories in the long-term with an overall average score of 3.9 (SD=1.4, MIN=2, MAX=2). Zürich 1 and Zürich 2 had the lowest mean (3.0), and Olten 2 had the highest (5.1).

4.2.5.3 Findings

Based on the results, the following key findings regarding the questions about situational memories and benefits were derived:

F4.5.1: The ability to restate the learning stations' topics after three months is slightly lower (0.1) compared to the measurement after the examination. Five Aarau students, one Olten 2 pupil, and three Zürich 2 students stated that they could list the content of all the learning stations completed during the LBML lesson better than after the examination.

F4.5.2: Only Olten 2 students believed they benefited from the LBML experience by developing cognitive expertise (4.4). Students from all other schools did not share this belief.

F4.5.3: The situational memories for the experimental groups in all classes were marginally satisfactory (3.9). The rock type lesson recall in Zürich 1 and 2 was the lowest reported, with an average score of 3.0. Olten 2 students scored 5.0 in their belief that they would remember the LBML trail's content when the content is encountered in a new context.

4.3 Discussion

In this section, the study results and findings are discussed concerning the chapter hypothesis and the research questions in Section 4.3.1, including the teachers' thoughts on the students' results. The limitations of the study are elaborated in Section 4.3.2 and Section 4.3.3 conclude the insights of this study.

4.3.1 Research questions

This section provides the findings regarding the hypothesis and the five research questions of Section 4.1.1, discussing the study outcomes and insights for each.

4.3.1.1 Research question 4.1

The main finding in regards to research question 4.1 – how teachers plan and prepare when developing an LBML trail – is that, regardless of new technologies, teachers' approaches were to implement the trail in a way they knew from previous teaching experience. Nevertheless, there were significant differences in the amount of work and skills required compared to classroom teaching or creating e-learning materials.

4.3.1.1.1 The structure of the planning and preparation

Known procedures from traditional field trip and novel procedures

Regarding planning and preparation, the main differences were observed in the field inspection. The teachers at Beromünster, Olten, and Aarau used well-known procedures from traditional field trip planning (Hemmer & Uphues, 2009) using mobile phones for taking pictures. The two Zurich teachers, experts in GIS and multimedia teaching, used mobile technology to capture and generate ideas as multimedia during the field visit, the recordings of which were permanently accessible to both of them, even after the field inspection. According to Puentedura's (2006) SAMR model, the use of mobile technology redefined their co-planning because simultaneous access and modification of ideas were previously inconceivable with analog note-taking in the field.

The structure of lesson planning was initiated as it is used in the classroom, chronologically and divided into main steps. Figure 42 depicts a schematic overview of the lesson planning's main steps. They are identified as essential in terms of guidelines for planning and preparing LBML activities (**F4.1.4).** During implementation, however, it became apparent that the rigid plan could not be implemented and that the phases effectively alternated with earlier steps. The reason for this was that in the process of planning, new ideas were constantly arising, which, when implemented in the design, had to be tested in the emulator and sometimes also outside on-site. The teachers argued that in contrast to the spontaneous possibilities in the controlled environment of the classroom, controllable through spontaneous interactions and oral exchange from the teachers' point of view, the uncontrollable LBML activities require, well-considered, and carefully implemented tasks with consideration of all contextual factors and occurrences in order to meet the quality requirements of teaching.

The results of the planning and preparing LBML activities including the minimal time effort (**F4.1.4**) revealed three main steps and are summarized as follows:

(1) Select a topic and determing the learning objectives, and the geographical area (> 1hrs).

(2) Explore the geographical area *in situ* and virtually (>2hrs.).

(3) Design and implement the content and test the solution virtually with the emulator and *in situ* (>2hrs.).

Planning and preparation through requirements analysis, on-site inspection, and implementation and testing

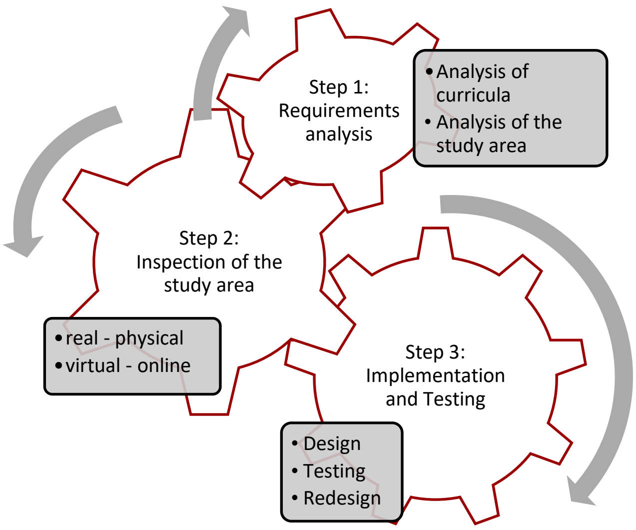


Figure 42 Planning and preparation of an LBML activity in three alternating main steps

Step 1: Requirement analysis

The first task contained an analysis of the curricula and decisions made about the choice of topic and the learning objectives. The four experiments show that teachers prioritized procedural and conceptual processes over factual knowledge, as per Krathwohl's (2002) taxonomy (**F4.1.1**). Procedural objectives required students to recall, clarify, carry out, analyze, differentiate, or judge artifacts. Conceptual objectives included recognizing, classifying, differentiating, and determining learning objects, including spatial thinking objectives with map readings or map analytics. Factual objectives were needed to respond to questions of surveys, analyze the surroundings to map distinct features, and evaluate phenomena. Metacognitive activities were mostly implicit or part of the debriefings. Digital communication, as a learning objective, did not play a role in any concept (**F4.1.2**). The lack of a communication channel to the teacher was criticized by some students who demanded direct feedback on individual tasks at the learning stations or wanted to report a technical problem (Zürich 1). As per Pask's (1975) *Conversation Theory,* continuous two-way conversation between teachers and students and among classmates was deemed essential. Social interactivity is one of five educational affordances of mobile devices (Klopfer & Squire, 2008; Squire & Klopfer, 2007) and serves as a means for accessing, discovering, discussing, and sharing findings (Uzunboylu et al., 2009). However, all teachers commented that the lack of digital communication was intended to foster soft-skills, such as self-responsibility, teamwork, peer conversation, and self-efficacy.

The second task contained location-specific research. This research determined the approximate spatial extent of the area by inspecting online maps and sketching potential routes using OMLETH-Creator. Further ideas were web inquiries of location-based services, such as geotagged photos and videos of multimedia sharing platforms, or interactive panoramas from distinct places, such as Google Street View. Peng, Chen, & Tsai (2010) used Google Street View as a preparation approach to plan routes. Their system allowed the viewer to watch and interact with the video as if they were moving through the planned route. This functionality is now part of Google Maps, and teachers could make use of it, for example for this step or as a complement to step 3.

Step 2: Inspection of the study area

The second step consisted of the *in-situ* exploration of the planned locations, which allowed for greater awareness of the characteristic of the content. It was noted that throughout the explorations, traditional methods, such as note-taking on paper material, were predominantly used. However, one Zürich teacher, who has expertise in teaching GIS, created a location-based survey app to record the discoveries in multimedia using digital note-taking by text, photo, audio, and video. Having developed greater familiarity with the software, the teachers agreed that, in the future, they take a tablet on explorations and directly draft the learning stations and include the notes with the OMLETH-Creator.

Step 3: Implementation and testing

Step three contained the task to choose appropriate technologies and implement the trail design, including the pedagogical approach, the creation of the learning stations and external systems based on the pedagogical decision of methodologies, modes of collaboration, modes of media, and modes of interaction and communication of teacher-student and student-student. Findings (**F4.1.2**) revealed that three LBML lessons contained deductive approaches with exercises incorporating previous teaching sequences in the classroom. Beromünster's lesson included an inductive teaching approach in which students had to construct rules and theories based on experimenting with the measuring instruments. Whether inductive or deductive, all teachers preferred self-regulated learning approaches in groups of two or three students. Therefore, no module contained an active communication concept involving the remote teacher or peers.

The last task contained the testing, modifying, and re-testing of the design, which effort was mostly underestimated. Virtual testings with the OMLETH emulator, which allowed to imitate the behavior of mobile devices, was reported as an important feature when text instructions with multimedia were designed. However, some teachers did not omit the testing on-site. The Aarau teachers preferred the tests on-site for two reasons: 1) It allowed them to observe the same context as the students; and, 2) It allowed them to test further location-based apps that did not have the possibility of an emulator.

4.3.1.1.2 Workload

Each teacher or pair of teachers in the case of co-tutoring encountered an average workload that was twice as great as one classroom lesson. The Beromünster teacher took the shortest time to plan and prepare, with a total of five hours to develop 12 learning stations, including scientific measurement tasks (**F4.1.3**). The two Aarau teachers took the longest time to plan and prepare, taking a total of 26 hours. Teacher A (from Aarau), with expertise in geodidactic methods, took up much of this time as she wanted to deepen the learning of geotechnologies and ensure the quality of the LBML activity was good. She undertook three field trips to review and perfect the implementation regarding content (story), task, and locations. However, in real educational settings, this level of investment on the part of Teacher A is not realistic. Teachers agreed that a realistic approach to implementing an appropriate and good quality designed two-hour LBML scenario would take at least five hours (**F4.1.4**), which is twice as much as a classroom lesson.

At least five hours preparation time for a two-hour LBML scenario

4.3.1.1.3 Teaching skills

Koehler & Mishra (2014) emphasize teacher knowledge and view the teacher as an autonomous agent with the power to significantly influence the appropriate (or inappropriate) integration of technology in teaching. The observation of the individual steps of the four experiments shows that planning and preparing an LBML lesson is critical. It requires a vast diversity of teaching expertise in technological, pedagogical, and content knowledge (TPCK) (Koehler & Mishra, 2014). Content knowledge includes knowledge about real-world examples of the curriculum content, including spatial awareness and creativity, to ensure that the right material is chosen. Technological knowledge includes hardware expertise on the latest generation of mobile phones and their sensor capabilities, such as GPS, batteries, mobile data use, and mobile data network coverage. Software skills are required to teach GPS, to handle a GIS, and to know or find the right app for the right purpose. Pedagogical expertise is required to choose appropriate learning objectives regarding prior knowledge of the content, teaching methodologies, organizational skills such as time management, environmental awareness about weather conditions, and safety issues along busy streets. Teachers' ability, therefore, fundamentally matter in the design of LBML activities, as discussed and argued further in Sailer et al. (2015).

4.3.1.2 Research question 4.2

Research question 4.2 concerns the question of movement analytics and how students perceive usability regarding positioning and web access. This was measured by comparing map-based VA results of the trajectories with usability feedback from the students.

As people spend most of their time indoors and only spend a short amount of time outdoors each day (usually less than 1 hour), they tend to overestimate thermal discomfort with negative consequences on well-being and satisfaction (Höppe, 2002), such as the attitude towards new technologies. Because usability and satisfaction in the context of mobile technology can be confused, the perception of the environmental and technological context was surveyed by direct observation and student feedback from the comments of Q1.8 of the Q1 survey. Therefore, the general environmental conditions concerned this research question RQ4.2 and were consequently also recorded as direct observation on site. Fortunately, all six experiments took place under dry conditions. The experiments in Zürich 2 and Aarau were performed under windchill conditions below 10 degrees. Some students expressed negative opinions in the open question of the experiment survey and complained about cold hands while handling the mobile phone. This might explain the low usage rates amongst students from Zürich 2 (23%) and Aarau (33%) of the OMLETH web application (F4.2.1). The four other experiments were conducted in pleasant conditions, and no specific negative or positive feedback was recorded. During Beromünster's experiment, cloudy conditions prevented the exercise with the albedo measurements. This pedagogical incident from the student perspective was not reported explicitly in the students' feedback. Instead, the general criticism of the pedagogical approach, which referred to the cognitive novelty of the application (Orion & Hofstein, 1994), may have implicitly addressed this environmental issue as well.

Environmental impact on students' perception

Overall accuracy of the location data

To investigate the overall accuracy of the collected location data, a review with the map-based VA showed generally good results at each experiment, with some outliers being detected up to several kilometers away from the path area. The statistical analysis revealed that the passively recorded movement trajectories showed strong accuracy at each experiment, with a median of six to twelve meters (**F4.2.4**), consistent with the reports of the related work (see Anthes, 2012; Lubbers, Albers, & Salim, 2010). The students rated the quality of positioning as reasonably satisfactory, expect Aarau's students who made consistently good experiences (**F4.2.7).** Aarau showed the highest mean (5.0), even though students crossed the old town consisting of high buildings and narrow streets, which normally face great GPS coverage problems, so-called urban canyon effects. Since OMLETH utilized the Geolocation API, Wi-Fi signals also contribute to the positioning, which was probably distributed very densely along the trail; thus OMLETH still provided results.

Impact of accessibility to the learning station on student perception

The accessibility to the learning stations was measured with the learning station request feature in the OMLETH-Player. The case of the highest number of learning station requests - 4.2 per station by students in Beromünster (**F4.2.2**) - is depicted in the two dense point clouds of Figure 28 (top picture) (**F4.2.3**) and is well represented in the Beromünster students' feedback, which had still satisfactory but relative to other classes rather lower scores positioning satisfaction (**F4.2.7).** The Beromünster students' behavior demonstrates a similar pattern as presented in Sailer et al. (2016), e.g., trying to request the learning stations as early as possible to minimize walking distance, resulting in an overlap of signals from learning stations behind and in front of the requester. The case of the lowest number of learning station requests, at 1.5 per station by Aarau students **(F4.2.2)**, is difficult to reproduce visually in the map-based analytics because the experimental group contained eleven students, making individual differentiation challenging. However, with exception to the one failed station request by one pupil at the beginning of the LBML lesson, no issues rose for other students (**F4.2.3),** which coincides with the technical feedback of an average score of 5.0 regarding the positioning (**F4.2.7).** Beromünster and Zürich 2 had the most substantial heterogeneity of the "requesters" (**F4.2.2**). This effect may be caused by the division of roles within the groups due to the complexity and number of tasks. The map-based VA of all experiments showed that more different users generally use OMLETH-Player at the learning stations than on the way between stations. The trajectories between stations often appeared isolated, although the students were walking in groups of two or three. This means that someone took over the role of navigator and led the group between the stations and another person was designated to gather and present the questions and guide the

Analytics on cooperative learning

tasks' problem-solving. Such cooperative learning roles were also found in the study of moving learners using the map-based VA (C. Sailer et al., 2016). Their examples identified individual learners as navigators with the pattern of constantly leading the group members of 2 to 4 seconds. A similar pattern of a group of students with related trajectories and a group leader is depicted at Zürich 2 in Figure 32.

Navigation and wayfinding analytics

The study of navigation and wayfinding skills, which can also have an impact on satisfaction and usability in case of difficulties, several patterns based on spatio-temporal, map-based VA were discussed in Sailer et al. (2015) and Sailer et al. (2016). The map-based VA showed mostly straightforward patterns between the stations that indicate no wayfinding problems. This interpretation can indirectly be confirmed that no comments on navigation and wayfinding were made in the experimental questionnaire. Incidents, such as Zürich 1's detour of one group (**F4.2.5**), were not mentioned. However, it remains speculative whether Zürich 1's group had temporarily lost the orientation or had intentionally made the detour due to other reasons, as observed with the "car incident" in case study 4 as well (see Section 3.3.3.2.2).

Analytics on technical incidents

Concerning the identification of technical incident patterns that affect the learning process, the temporarily poor positioning of a student in Olten 1 was interpreted as a serious incident according to the map context (**F4.2.6**). The analysis of the map showed that the incident occurred close to the station, where typically, the GPS signal is disturbed due to the interference of electricity (see Figure 33). This interference was stressed in the technical feedback of the questionnaire by the student as well. This example confirms that the value of VA, including several base maps, achieves the identification of systematic and relevant outliers that impact the student's learning process. This capability allows teachers to intervene in real-time, or at least to address and discuss them as the teacher of Olten did during the debriefing.

Analytics on web access interruptions

The students reported consistently good web access (**F4.2.7**). The study of web access interruptions is discussed in Sailer et al. (2016), which concluded that gaps in the data could have several causes due to technical limitations or intentional interaction of the user. Web access interruptions in the OMLETH-Player are recognized of the system and mentioned to the user but not stored on a database and, therefore, not available in the semantic trajectories like the learning station requests.

The research of learner's movement trajectories and learner's usability perception regarding positioning and web access has shown that overall usability perception strongly correlates to the perception of the phone's positioning performance. In tour-like activities with linear ordered learning stations, the results have shown that positioning performance is well observable by map-based VA of the spatial position of the points in 2D and 3D. It can be concluded that map-based analytics of the learner's movement trajectories in the combination of a 2D and 3D view can explain the students' usability perceptions of LBML activities effectively.

4.3.1.3 Hypothesis 4.3

Hypothesis H4.3 that the intervention of an LBML activity leads to improved examination outcomes was **confirmed.** Results from this analysis reveal that an LBML lesson of 90 minutes within a teaching sequence of six weeks leads to significantly improved examination results with a statistical power of d= 0.38 (**F4.3.1**). The nested group factors school, class, or teacher had no significant effect on the examination results. The study's effect size just below the hinge point of 0.4 was the average effect size of all 138 interventions related to learning achievement, based on Hattie (2013). A teacher typically has an effect size ranging from 0.2 to 0.4. Effect strengths higher than 0.4 represent the zone of desired effects, which improves the learning performance to such an extent that it can result in noteworthy differences in the real world. Comparable educational activities of Hattie's (2013) metastudy are presented in Appendix 1.

Significant improvement in the learning outcomes with an average effect size of d= 0.38

Regarding the individual classes, those groups with higher sample sizes continually exhibited higher average exam grades for the experimental group compared to the control group (**F4.3.2**). Zürich 2 and Olten 1's control groups had critically low test sizes for statistical analysis. Both groups contained only four students due to dropouts. Olten 1 had an equal average of the exam grades, while Zürich 2 had a lower average examination grade for the experimental group. These two classes also showed worse results for the self-assessments (discussed in Section 4.3.1.4). The exam results could not conclude whether the testing differences and self-reports represented a statistical artifact, or whether the differences were real and compensated for by the debriefing and special effort in learning for the exam.

When comparing the pedagogical approaches, Beromünster, who used an inductive, inquiry-based approach for the LBML lesson (**F4.1.2**), showed the highest difference between the averages of the examination scores. This indicates that the students need to actively – through trial and error - construct the meaning of the theories of the climatic elements. This finding confirmed the value of action learning with real problems propagated by Bruner's (1966) principles of the spiral curriculum, and Aebli's (1983) and Gagné's (1985) problem-oriented frameworks on intentional or purposeful learning.

4.3.1.4 Research question 4.4

Research question RQ4.4 concerns self-assessment through questionnaires. The goal was to find evidence that learners who attended a location-based mobile learning lesson, within a regular teaching unit, would demonstrate higher self-assessment, especially in cognitive ability. A summary of the repeated measured self-assessment scores of understanding, motivation, and attitude is depicted in Figure 43 as boxplots to provide evidence of the overall outcome of the learning perception within the students.

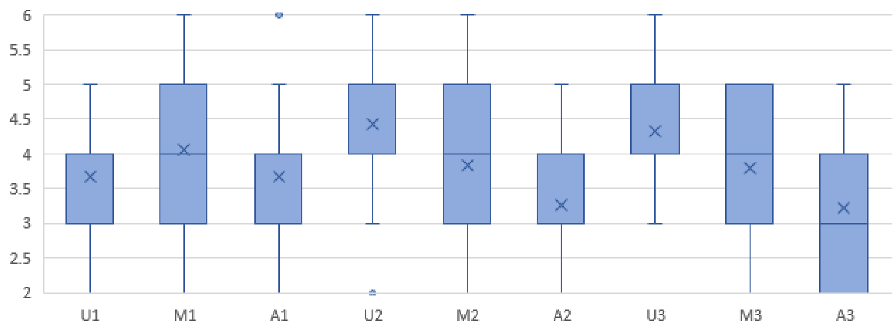


Figure 43 Self-assessment scores throughout the longitudinal study of understanding (U1, U2, U3), motivation (M1, M2, M3), and attitude (A1, A2, A3) for the experimental group following the experiment (1), examination (2), and the long-term survey (3) as box plots.

Experiment survey (U1, M1, A1)

Efficiency of learning matters

The experiment survey revealed that understanding was reported as lower than motivation (**F4.4.1**). Some negative statements in the qualitative feedback regarding understanding revealed explanations of this difference. For instance, some Beromünster, Olten 1, and Zürich 2 students compared the LBML activity with an informal activity that is “inconvenient for serious and efficient learning”. The students took the “amount of mediated knowledge” as the key parameter for good teaching and concluded that an LBML activity conveys much less content compared to a classroom lesson or needs significantly more time and resources than a classroom activity. Beromünster's teacher also mentions the Matura stress factor. His students faced a hectic and stressful semester owing to the coming Matura. As a result, well-versed students, who use well-rehearsed learning strategies to pass the exam with minimum effort and maximum yield, complained. The answers were collected before the debriefing activity in the classroom, where the field experiences were shared, reflected, and conceptualized abstractly within the whole class.

Deep learning through reflection

Beromünster’s LBML debriefing had a significant impact. Some of the students reported that the oral classroom exchange with students from other groups, combined with the teacher's inputs and additional assignments, was crucial for the understanding and elaboration of the topic. This finding aligned with Kolb's (1984) four-stage cyclical model for experiential learning - concrete experience, reflective observation, abstract conceptualization, and testing in new situations and Brockbank et al.'s (2017) empirical findings. Brockbank et al. emphasized that in ill-structured experiential learning scenarios with technology and the lack of immediate feedback, knowledge acquisition needs to be elaborated within a reflective process to prevent misunderstandings. Furthermore, the “designed” novelty space plays an important role in the learning outcome, according to Orion and Hoffstein (1994), which consists of three components, namely cognitive, geographical, and psychological novelty. Concerning the study, the geography of the area was familiar to all students. The psychological novelty that refers to the readiness was tried to hold down by introducing the OMLETH-Player web app and the length of the activity prior the activity and during the activity by indicating the expected workload and learning objectives at each learning stations. A further psychological factor, the general interest in Geography as school subject or the specific interest in the topic was assessed as satisfactory, which therefore should not have shown any negative impact (**F4.4.7**). Using OMLETH as new technology and LBML as a new learning approach was evaluated satisfactorily by the technical feedback, with an overall average score of 4.5, and in Beromünster’s group, with an average score of 4.7 (see Section 4.2.2.2, Table 12). Consequently, it can be concluded that the weak self-assessment of the performance of cognitive outcomes was partly caused by the lack of cognitive readiness / prior knowledge. This conclusion fits perfectly with the concept of Beromünster's teacher, whose aim was to introduce scientific measuring instruments and scientific measuring methods by self-discovery, and not via previous theoretical explanations in the classroom. However, even Piaget (1972) overestimated the thinking ability of adolescents and realized that most adults use formal operational thinking only in areas in which they already have a greater interest or a very high level of experience. The moderate interest in the subject, which is reflected in the attitudes throughout the study (see Figure 43), the first-time experience with OMLETH, and the lack of experience, in particular at Beromünster, may, therefore, be the main reasons for the weak cognitive self-assessment after the LBML activity.

Examination survey (U2, M2, A2)

The experimental group reported a statistically significant increase in the cognitive outcome after the examination compared to after the experiment (**F4.4.3**), which depicts the boxplot U2 (understanding after the trail) and boxplot U1 (understanding after the examination) in Figure 43. In addition, the experimental group assessed the cognitive learning outcome after the examination as approximately equal to the baseline. (**F4.4.3**). An obvious explanation is the reinforcement effect of the debriefings in the post-trail activities, where learning experiences and digital collected findings and responses where shared and reviewed in response to the overarching theories and learning goals. Three students explicitly mentioned the valuable function of the debriefing, which was very beneficial for the clarification of open questions and the general understanding. Furthermore, two students who explicitly reported that they worked extra hard for the exam to achieve the personally expected cognitive ability was a second reason, as well as the exam effect itself a third reason for the increase with an average of score difference of 0.7. However, motivation M2 declined with an average of score difference of 0.3, and attitude A2 dropped with an average of score difference of 0.4. While LBML activity has shown some immediate effect in affective assessments, the lack of relevance after the examination may have revealed the real intrinsic affection.

Long-term survey (U3, M3, A3)

Figure 43 depicts that the long-term survey average scores of the experimental group for the understanding of U3, motivation M3 and attitude A3 yielded the same values as in the examination survey (U2, M2, A2) and based on the finding **F4.4.6** the same scores as in the control group at the same time. The students' self-assessments of their cognitive and affective domains did not change on average over time, nor were self-assessment differences found between the experimental and control groups. Thus, the LBML activity did not show a sustainable effect on the pupil's self-assessment in the long-term. The low affective values after the examination and after three months could be due to the general intrinsic motivation of the adolescents. At the age of 16 - the average age of the 107 students in this longitudinal study - intrinsic motivation is lowest among adolescents (Gnambs & Hanfstingl, 2016). In addition, low motivation can be a consequence of emerging extrinsic, performance-based constraints and regulations during youth development, such as school examinations, which undermine intrinsic motivation to learn. When these constraints are removed, as in the example of this study in the exam survey (M2, A2) and the long-term study (M3, A3), the low affective values towards a learning subject become apparent.

The reflections of the experiment by students of the experimental group obtained that another topic, also to be carried out as LBML activity, was answered from great approval to great rejection (**F4.4.8**). As the qualitative feedback showed, there were strong supporters of mobile learning, such as the Olten 2 students, but also strong opponents, such as Zürich 1 students. This evidence significantly differs from Abe et al.'s (2005) field experiment more than a decade ago, even before the release of the first iPhone (see Subsection 2.5.2) where, despite usability issues, 95% of the recruited participants stated they would repeat a similar program. The circumstances were, however, different. Abe et al. (2005) reported that they had no problems finding enough participants because the novelty of technology impacted them. Participants in this experiment, on the other hand, had compulsory attendance, and none of their responses referred to the novelty factor.

The way of examination influences learning

In the case of an examination as an LBML module (**F4.4.8**), the average students would not actively explore for similar examples from everyday life but would at least repeat an existing LBML module as exam preparation. This finding confirms Bloom's (1956) thesis that assessments, learning objectives, and activities in courses must be closely aligned so that they reinforce one another (Krathwohl, 2002). As long as exams are extrinsic triggers, it is in the nature of the game that students optimize the preparation for the exam, in the case of an LBML exam, they would practice with LBML activities, as discussed in the previous section of the experiment survey results (**F4.4.8**).

The quality of this self-assessment

The results of the self-assessment questionnaire are reported views and therefore are subjective. However, to ensure the comparability of the results, this study referred to suggestions concerning objectivity, reliability, and validity of related work. Objectivity is fulfilled because the response option is structured with a limited set of options, such as the Likert scale (Sacher & Rademacher, 2014). Reliability is granted since student self-assessments are generally shown consistently over a range of tasks and across questionnaires' items with the same construct (Ross, 2006). However, reliability also depends on the number of items (Sacher & Rademacher, 2014), which were weak in this study. Blatchford (1997) compared students' response validity and found that self-assessments were highly correlated with standardized tests at age 16, but not from 7 and 11-year-olds. High validity can be achieved when students are well instructed (Ross, 2006) and are conscious of the contents, the learning goals, and the expected performance level (judged criteria) (Sacher & Rademacher, 2014).

4.3.1.5 Research question **4.5**

Research question RQ4.5 sought to establish if learners from the experimental group benefit from and remember the learning content of the location-based mobile learning lesson three months after the LBML trail. Questionnaires were used to gather data on this research question.

The ability to recall information of the learning stations subjects three months after the trail is only slightly lower than after the examination **(F4.5.1)**. This finding shows better results (less decrease) than the values of the Ebbinghaus model with the Curve of Forgetting, which suggests a decline in memory retention over time (Murre & Dros, 2015). However, five Aarau students, one Olten 2 pupil, and three Zürich 2 students stated that they could list the content of all the learning stations completed during the LBML lesson better than they could after the examination. This might be theoretically controversial and could point to the student's ability to self-assess the memory or the validity of the questionnaire. However, theoretically, the results of the few students could be true considering that strategies for better memorization exist, such as the mnemonic techniques or active recall due to Matura examination in the case of the Zürich 2 students. In addition, the location-based mobile learning content remained in the schools that students pass through daily to reach or leave school. One student from the first case study in Chapter 3 mentioned precisely the possibility of repeating the experience as a personal benefit of location-based mobile learning that he was reminded of the contents and experiences while driving through the places visited each day. Students from Aarau and Olten 2 were the only ones who claimed they could still list the content of all learning stations completed during the LBML lesson. Beromünster was the only group where all the students stated they could explain at least a portion of the climatic elements station information. Noting this ability amongst the students, the Beromünster teacher acknowledged the importance of using LBML lessons in the future.

However, the students did not share the same enthusiasm or beliefs. They evaluated their situational memory performance when the learning content is encountered in a new context as marginally satisfactory (3.9) (**F4.5.3**). Regarding the concrete groups' memory performance belief and their corresponding learning subject, the trail with the examples of rock types was considered the lowest gain in terms of situational memories performance amongst Zürich 1 and 2 students, while Olten 2 students strongly believed that they would remember the urban settlement trail when the learning content is encountered with a concrete example in a new context. The second part of this research question asked about the cognitive benefit of the LBML experience. This was evaluated with a score, on average, of 3.6 (viewed as low), compared with the self-assessment about understanding, which scored, on average, 4.3. Olten 2 students, who inquired the topic of settlement **(F4.5.2),** were the only ones to report a positive cognitive benefit (4.4) and to report generally positive results. The teachers considered the results for this research question to be reliable and valid. However, the results are not verifiable. To overcome this limitation, it is necessary to test the students for their recall abilities of concrete learning content. Unfortunately, the teachers were not available to undertake this step as well.

4.3.2 Limitations

The strength of the study was the real-world approach it offers, including teaching, learning, and assessing under real conditions. There were, however, limitations and issues identified in this approach.

Generalizability

The study design sought to simulate how geography teachers from Swiss Matura schools typically use LBML technology, such as OMLETH. Student participants, therefore, needed to be enrolled in Swiss secondary schools and be in grades nine to twelve. With this sample group, the study of variation by age group would be futile. Also, the participants were enrolled in geography courses only, meaning that the findings may not be generalized to other subjects according to Hattie's (2013) synthesis of meta-analyses on the determinants of student achievement.

Task design

The pedagogic approach of LBML can range from a confirmation inquiry where the problem, procedure, and solution are completely guided by the teacher, to an open inquiry where all three phases are initiated by the student (Tan et al., 2018). However, (J. S. Brown et al., 1989) claimed that “Knowledge is situated, being in part a product of activity, context, and culture in which it is developed and used” (p.32). The teachers of the six classes did not pay much regard to this central contribution of outdoor learning. The task’s designs allowed only a low level of student agency to determine the learning process and content. Three of the four LBML lessons were based on structured inquiries with the concept of applying the knowledge and skills learned in the classroom. The remaining one, Beromünster, was according to the proposed taxonomy of Tan et al. (2018), a guided inquiry because procedure and solution were not pre-defined and part of the learning tasks. Regarding free movement, the designs of Olten and Aarau incorporated a strict sequential order of tasks. Beromünster’s design featured a quasi-sequential order due to the geographic arrangement and natural barriers of private properties. Only the geogame of Zürich 1 and 2 employed a non-linear task approach that allowed the students to make their own decisions about where to go. However, the underlying pointsification influenced student behavior as well. An exploratory student-led inquiry with open research questions, procedures, and solutions where the learning stations were, for instance, merely back up repositories for theories, feedback, exchange, etc., did not occur in this study.

With the experience and insights gained from the study, different and more open designs would possibly emerge with the same teachers. Connecting teachers and learners using digital communication to ensure scaffolding would allow designs with ill-structured inquiry activities, the visit of learning stations voluntarily, or according to interest and current situation.

Learning analytics

One important goal of the study was to investigate the detailed learning process during the LBML activity, which this research contributed with map-based visual analysis and descriptive statistics of the collected trajectories and learning station requests. The data allowed a near-precise analysis of the students' place-related actions regarding movement and spatio-temporal relatedness to others. Data from other applications, such as external productivity tools or assessment tools, could be added to the analysis, creating a relatively good understanding of the learning experience and making learning activities tangible and controllable in combination with the movement trajectories. However, no insight was obtained into the interaction and communication on-site and online between the students within a group or between groups. The analytics did not retrieve insights into the transmission of knowledge nor true and false understandings.

Examination

Classroom examinations were assumed as the most valid form of testing the learning outcome because they are part of the semester grade and the Matura graduation for direct entry into universities. However, the study design did not allow to have any influence on the assessments' content or on how teachers assessed achievement to determine final grades. Furthermore, the comments and the question about the repetition of the module, in the case of an exam as LBML design, showed that the students do not perceive the examination as a representative example for solving real problems.

Questionnaires for self-assessment

Self-assessment questionnaires were selected, as a methodology, to obtain insight into learning progress and allow students to self-assess their state of mind at different points throughout the learning process (experiment, examination, and three-month-after measure). Self-assessment in educational context serves the purpose of improving learning and ensuring greater achievement (Andrade & Valtcheva, 2009; Schunk, 1996). Self-assessment is a prerequisite to contribute to higher self-efficacy, greater intrinsic motivation, and more substantial achievement (Schunk, 1996). Andrade & Valtcheva (2009, p. 13) stated: "Students who set goals, make plans to meet them, and monitor their progress tend to learn more and do better in school than students who do not." In this study, teachers used diaries and reflection journals to assess their work cognitively and affectively in a qualitative way. Quantitatively, standard questionnaires were also used. Goals and goal orientation can be measured, for instance, by the Questionnaire of Motives, Expectancies and Values, part A (MEVA) (Tapia, 2005), with 76 items. Affective effects can be measured by the Emotion and Motivation Self-regulation Questionnaire (EMSR-Q) (Alonso-Tapia, Panadero Calderón, & Díaz Ruiz, 2014), with 36 items. However, the preliminary study showed that students were not willing to participate and complete such a lengthy questionnaire. As a result, the longer version questionnaires was withdrawn, and opted instead for a shorter style, to achieve a high number of returns. Concerning this study, validity threats and biases of the results were examined by the teacher and discussed in the semi-structured interviews.

Ethical problems and geoprivacy issues

Ethical issues included the participant's permission to be monitored for research purposes and their right to choose when monitoring occurred. This was particularly relevant for student participants who are minors (Sharples, 2009). The data was anonymized using pseudonyms. However, movement trajectories contained the physical location of the pupil during the LBML lesson, and due to the Bring Your Own Device (BYOD) - concept, there was no control over the remaining apps and their configuration regarding data privacy. With data mining techniques, it is possible to identify real persons based on their trajectories (Krumm, 2009). Even if the user is anonymized (Bettini al., 2005), detections of unique places and profiles created from other data sources can uncover user's identification (Duckham & Kulik, 2010; Keßler & McKenzie, 2018). Another ethical problem was that the study was part of an evaluated curriculum, and, therefore, participants may have felt compelled to participate (Sharples, 2009).

4.3.3 Conclusion

This LBML study aimed to understand the individual and collective processes of learners experienced through the obtained results of intervention with LBML. Using an experimental design, changes in cognitive and affective aspects of the competencies of secondary school students were observed and analyzed across different Swiss Matura schools over a long period.

In implementing the design, a first analysis of the planning and preparation of LBML lessons identified five essential steps. These were: (1) Selecting a topic and determining the learning objectives; (2) Choosing the geographical area, (3) Exploring the geographical area *in situ* and virtually; (4) Implementing the content; and (5) Testing the implementation *in situ* and virtually. Teachers who tested their designs virtually using the OMLETH emulator or on-site to simulate the behavior of digital content in OMLETH had no serious design problems to report when the students ran the trail activities. Hence, this research shows that teaching LBML lessons requires a greater commitment, in terms of workload, and a broad set of skills and knowledge regarding content, pedagogy, and technology.

Second, map-based visual analytics patterns of the learner movement trajectories were compared with the usability perceptions of the students. The findings of map-based analytics of the learner movement trajectories revealed a valuable model to gather insights into the students' usability perceptions of OMLETH regarding positioning and insights in spatial abilities such as orientation or wayfinding skills.

Third, the main research question dealt with the effect on examination results of 90-minute LBML lessons within a teaching sequence of six weeks. The most promising results showed that even brief exposure to learning through an LBML lesson leads to statistically significantly better school grades.

Fourth, the statistical analysis of the self-assessment process regarding understanding, motivation, and attitude manifested no sustainable effects after the examination or in the long-term. However, qualitative answers point to the relevance and importance of discussing the learning experiences in debriefings, ideally both outdoor during the trail and post-trail in classrooms. The technology-enhanced debriefing after the LBML lesson with the OMLETH-Viewer, delivered new didactic forms based on a combination of cognitive memories (through menatal maps) and personal data from OMLETH and other productivity tools or collector apps with the aim to decontextualize the experiences with collaborative reflections in order to emerge them into new concepts in response to the overarching questions.

Finally, the ability of participants to recall the learning stations' topics, at a date after the experiment itself unveiled different, partly contradictory results in terms of self-estimation and contained no evidence of the impact on the performance of the recall of factual knowledge through the LBML experience. A design with several pre- and post-tests would gather more insights into the value of the situated learning approach.

5 Conclusions

This dissertation has presented the development of an LBML system that creates, plays, and reviews LBML activities. It has also provided an evaluation that demonstrates that LBML improves learning cognitive outcomes. During the research, a web-based educational system of three main applications was developed using cloud-based GIS technologies. Using research-based design methods, teachers and students from secondary and tertiary educational institutes then tested this system and technology in four case studies. An experimental study provided insights into the planning and preparation process of an LBML activity and the cognitive and affective outcomes, including the spatial thinking processes of LBML. The most promising results showed that LBML leads to statistically significantly better school grades and the promotion of spatial thinking processes in descriptive, analytical, and inferential ways. Another important result showed the diversity, complexity and high demands on teaching.

This chapter draws overarching conclusions from the four case studies described in Chapter 3 and the long-term study in Chapter 4. Section 5.1 first revisits the research questions (see Section 1.1) and then summarizes the outcomes of this research. Contributions and potential applications are discussed in Section 5.2, followed by the dissertation's limitations in Section 5.3.

5.1 Summary and discussion

This dissertation comprises work on the development of a system for location-based mobile learning (LBML) and its evaluation with empirical studies in real-life educational settings. The LBML intended to promote spatial thinking and sustainable learning beyond the summative assessment of a teaching sequence. Four case studies were designed and implemented with design-based evidence to achieve the research goal. They are presented in Chapter 3.

In the first case study, an intervention was devised, and the prototype was evaluated in a semester course with architecture students from ETH Zurich (see Section 3.3.1.2). In the second study, an introductory session of a research camp was conducted as an LBML trail to collect and analyze the pupils' movement trajectories using a map-based visual analytics approach in GIS software (see Section 3.3.1.3). In case study 3, the findings of the case studies 1 and 2 were used to undertake the ETH semester course again (see Section 3.3.2.2). The fourth case study was a mixed design study conducted in a vocational school with apprentices and sought to evaluate the learning achievements in a written classroom exam and observe the sustainability and long-term memory effects of the LBML treatments. In Chapter 4, the study design of case study 4 was used to investigate learning achievements on a larger scale with several classes (see Section 3.3.3.2). The between-subjects design evaluated an LBML activity by testing the cognitive learning outcomes on an examination. The within-subjects design evaluated an LBML activity by self-assessing the abilities to recall information or recognize knowledge. The remainder of Section 5.1 revisits the study's research questions (see Section 1.2) and summarizes and discusses how this research has addressed them.

5.1.1 MRQ1: Technology

The first research question sought to identify the key features of an LBML system with advanced GIS that can support the entire LMBL teaching and learning processes in project-based settings. This dissertation has presented an LBML system that provides an integrated, modular web platform for creating, playing, and reviewing LBML activities. This system can be used by educators from different disciplines and schools of different educational stages.

5.1.1.1 Creator interface

The creator interface was developed within four iterations of development and testing, including those conducted in the four case studies, and the usability testing in the experimental study (see Chapter 4). The interface allows teachers to create georeferenced multimedia content based on a collection of interactive basemaps. The learning content is spatially represented as a point or polygon features. The novelty of the interface is characterized by the integration of the following GIS features:

- Features for editing the module's multimedia content as a point or polygon representations with different functionalities (i.e., learning content, multimedia collector, information or safety warning spots, and links to external services) and a tool to review the design as a smartphone or tablet emulator.
- Features for managing content-allocation to the maps, such as different basemaps (e.g., topography, satellite imagery, street, OSM), the route and time planners, and distance measuring tools.
- Features for managing the module and its contents, such as exploring, sharing, co-creating, and linking external services, e.g. messaging or productivity apps.

5.1.1.2 Player interface

The player interface was developed and evaluated in parallel with the creator interface. The player interface allows users to play the modules using the mobile web browser in the individual or group modes. Navigation and access to the situated multimedia content are assisted by location sharing through GPS, Wi-Fi, and Cell-ID for outdoor use. The case studies with the architect students (see Section 3.3.1.2 and Section 3.3.2.2) revealed that different types of maps are essential in LBML activities for orienting, situating the content, and improving spatial thinking. It also demonstrated the need for a communication interface to enable online conversations. The following key features characterize the interface:

- Features for location sensing information such as the position accuracy and speed display, and mobile data connection information such as the web access display
- Features for context information such as the four basemaps (i.e., topography, satellite, street, and OSM).
- Features for connecting the communication and documentation services.
- An analytics service for collecting users' movement data to monitor the activities and prevent safety issues, and review the learning activities.

5.1.1.3 Viewer interface

In the beginning, the viewer interface was not within the scope of this research. However, in case study 2, it became apparent that a separate interface was necessary for tracking and reviewing the activities. The interface allows creators and players to watch and follow the real-time user interactions as overlays on 2D and 3D maps. This is achieved through the analytics service, and the stored data is then used for debriefing and post-processing. Case study 2 identified and the case studies 3 and 4 confirmed the need for an easy-to-use approach to verify the design and evaluate the activities. The results of the experimental study (see Section 4.2) demonstrated the value of the viewer components in the following ways: for real-time support of the learners in spatial orientation and wayfinding issues; for real-time control of learners' behavior to adapt teaching interventions; and, for assessing positioning issues of GPS.

Furthermore, the viewer components supported debriefings to recapitulate the learning experiences and to self-assess the teaching design in the case of the repetition of the module. The results show that both teachers and learners require access to the data to be able to review the activities. The following features have been deemed critical components for the review of LBML activities:

- Real-time access for the map-based visualization and metadata of the user's movement trajectories in 2D and 3D for monitoring the positions, speed, and metainformation of the user.
- Exporting data features for the user data and learning content in open file formats to use in other GIS applications, such as Google Maps or OpenStreetMap, that support standardized data formats.

5.1.2 MRQ2: Teaching

The second research question sought to identify the key requirements for preparing and executing an LBML lesson for real-world contexts and establishing to what extent LBML teaching differs from other teaching strategies. Such strategies include classroom instruction, e-learning courses, or excursions without mobile technologies. From various exploratory and experimental studies within this research, patterns in teaching preparation and execution have emerged as critical to effective teaching. The preparation and execution results (see Chapters 3 and 4) are based on participant observation and an unstructured interview at the end of the study.

5.1.2.1 Preparation

Teacher preparation patterns across this study were relatively similar. Time spent designing the activities ranged from 90 minutes to three hours, and a pattern of five common action steps was identified in the design process (see Figure 42). The first step included a requirements analysis of content, target group, and learning objectives. The next step involved identifying the activity location. Some of the teachers sketched potential learning stations in OMLETH and took the drafts with a tablet to identified sites. Field-notes regarding considerations of hardware, apps, content, and important places were taken in the form of handwritten notes or mobile notes. Teachers who prepared the digital draft design in the OMLETH-Creator used it to verify and adjust the locations and content. After this, upon returning to the office, some teachers created the learning tasks directly in OMLETH, and others used their personal working environment to develop and structure the learning content before they copied the results into OMLETH. Once the learning design was implemented, it was tested, adjusted, and re-tested, usually by verifying and simulating the module, using the emulator. One teacher in the experimental study conducted on-site testing three times.

The total workload to develop a module ranged between five and 26 hours. Regarding the individual steps, for most teachers, the field inspection constituted the most significant workload. The main differences between classroom instruction and the e-learning course are evident in the field inspection and the review conducted with the emulator or in the field. The workload to conceptualize the design of the LBML lesson is similar to the traditional teacher-guided excursion. Still, the precise planning and lack of flexibility were reported as the main differences, although OMLETH allowed for adjusting the content during the activities. As field inspection is standard in traditional field trip didactics, none of the teachers had considered inspecting the test site exclusively with tools such as Google StreetView. The teachers' common opinion was that a visual channel is insufficient for contextual perception, thus making an on-site visit inevitable, despite the average workload of five hours for a two-hour lesson. The teachers further explained that outdoor lessons, which mainly refer to traditional excursions, were considered as unusual activity in the curricula. The teachers were, therefore, familiar with the considerable amount of work and many necessary organizational steps required for outdoor lessons. Despite this, teachers expressed their willingness to invest the same effort and workload in LBML teaching to traditional excursions, as such lessons are unique events, happening only once or twice a year.

5.1.2.2 Execution

The teachers' coaching behaviors revealed two patterns. The first role was taken by architecture lecturer from case studies 1 and 3 (Chapter 3) as coach and communicator. He always carried out initial instructions on-site to solve the remaining questions and problems face to face. With more experience in teaching LBML, he supported the students with scaffolding per messaging app and fostered online communication with one another and him. The second role was represented by the secondary school teachers in the experimental study (Chapter 4) as of promoter of independent learning and as a remote follower via the OMLETH-Viewer web app. Despite the knowledge of messaging apps, the teachers did not want to engage in formal exchanges among pupils. The approach was to encourage pupils to solve the tasks independently without teacher assistance. However, according to the principle of independent and self-regulated learning, the teachers allowed private group chats among pupils so that they could freely and informally communicate with one another. No difference in teaching roles was apparent when using the OMLETH viewer to visualize and enrich classroom review sessions with detailed information occurring in the field, including privacy considerations.

5.1.2.3 Teaching abilities

The main difference in teaching abilities in the LBML context compared to others was the importance of spatial cognition skills and the new affordable didactics of teaching and learning with mobile phones. According to Klopfer & Squire (2008), the five affordances include "portability, social interactivity, context sensitivity, connectivity, and individuality" (p. 95). The phone's affordances portability and individuality were achieved through the OMLETH's architecture approach throughout the research of this dissertation. The main differences were generally in student involvement, the level of student agency in the learning tasks. For such well-structured problem-solving tasks to examine classroom theories, the cooperation with others outside the learning groups was not essential. But, for ill-structured scenarios of large-scale phenomena to find, for instance, spatial patterns, interactive designs were required to make use of the discoveries and interpretations of others. The reported example of case study 3 made use of social interactivity in several aspects. For instance, to create an online debate between the students about the same building from different physical perspectives. The individual groups of learners were distributed in remote positions around the building and were required to take one of these perspectives. The entire debate and exchange of ideas and discoveries between students were conducted exclusively via the online messaging tool, which was handled by the lecturer. The design needed careful preparation and required a lot of conceptual work. At that time, the lecturer had considerable experience in creating LBML designs, as he had created more than ten designs. He also made use of a mobile phones' context sensitivity to gather geo-referenced data using the phone's position sensors. Location-based data collection was also part of the experiments of Zürich 1, Zürich 2 and Aarau of the experimental study. These teachers brought extensive experiences from field-based education using mobile GIS. However, enhancing outdoor learning with mobile phones means many new requirements for teaching. This dissertation has shown that to effectively implement LBML, the following abilities are needed: (1) geographical understanding of the natural environment in terms of value-added in teaching within this context, whilst also understanding potential safety and legal risks; (2) map-reading and spatial reasoning skills; (3) technical abilities and knowledge of GIS, GPS and ICT cloud technology skills; (4) cognitive literacy of multimedia, cognitive load, and information processing; (5) pedagogical literacy of the learning paradigms and associated teaching strategies such as instructional design, cognitive apprenticeship, well-structured to ill-structured problem-based learning approaches, and social and conversational learning approaches; (6) creativity, endurance, self-efficacy, and positive attitude towards rapidly changing contexts and conditions; (7) organizational literacy to co-create LBML activities with other teachers and to manage time and resources adequately; and, (8) reflection-in-action literacy. The above skillset shows that teaching LBML is demanding and that the teacher plays a fundamental role in the design and implementation of LBML activities and students' perceptions of this learning process.

5.1.3 MRQ3: Learning outcomes

The third research question MRQ3 sought to establish how learning outcomes differ between traditional classroom instruction and traditional classroom instruction combined with the LBML intervention. Bloom's (1956) taxonomy was applied for the examination of the cognitive and affective domain. The investigation of the spatial reasoning aspects included the analytical and inferential functions from the National Research Council (2005).

5.1.3.1 Cognitive aspect

The cognitive aspect of learning included the recall or recognition of knowledge and the development of intellectual abilities and skills. Examples from case study 1 showed that cognitive challenges were reported because, firstly, the required knowledge and skills on-site did not correspond to the theory from the classroom and, secondly, there were no possibilities to obtain the results among the students for comparison possibilities or at least explanations for incorrect answers. Therefore, feedback and conversations mattered. Students in case study 3 rated as 'very valuable' the lecturer's direct feedback to individual students or exemplary feedback on a specific topic within the class chat. Furthermore, the discussions and comments conducted in the seminar room were reported as essential for clarifying the students' remaining questions. The use of the cognitive apprenticeship model with initial intensive instructions and guidance by the teacher (in the classroom or on-site at the start), followed by a slight degradation of interaction and guidance over time, was observed as an ideal teaching strategy. All of the studies showed increased engagement and commitment to the cognitive learning outcome if multimodal learning occurred and was stimulated by particular tasks. These tasks included physical work (even the collection of physical materials) or multimedia, such as pictures, maps, podcasts, video, or multimodal communications, including orality through debates on-site and digitality through online conversations.

The main research question MRQ3 concerned the cognitive effect of LBML on the examination results, which was investigated in the preliminary study (Chapter 3) and the main study (Chapter 4). The exam results of both studies revealed higher scores for the students who had participated in the LBML activity. The pupils of the main study performed significantly better with an effect size $d = 0.38$, which is slightly below the hinge point of the desired effect zone (Hattie 2013). Of particular interest in the main study was that the class was given the highest degree of learner agency, according to Tan et al.'s (2018) taxonomy, which had the most significant positive differences in the exam. The self-assessment evaluated the sustainability of the LBML activity with regards to the cognitive outcome. It, however, revealed low scores immediately after the LBML activity, but significantly better after the activities' debriefing and exam, which remained stable three months after the exam. The scores after the exam and after three months did not show significant differences compared to the baseline. The students evaluated the cognitive benefits of the LBML activity on exam achievement as rather low, and some experimental-group pupils emphasized the relevance of the debriefing to resolve open questions and correct remaining misconceptions. After three months, the students' ability to remember individual situations, and the subjects studied was mostly strong, yet they assessed this ability as only marginally satisfactory.

5.1.3.2 Affective aspect

The affective aspect of learning included attitudes and motivation. Examples with the architecture students (Chapter 3) showed that a regular alternation of classroom and field education promoted not only the understanding but also the meaning and purpose of the learning content, affecting motivation and attitudes towards the learning subject. Poor motivation occurred primarily through the so-called psychological novelty, according to Orion and Hoffstein (1994), in the first field visits because students felt unaccustomed to the new methodology of LBML and the overall organization of the lesson. This confusion or unfamiliarity centered on being unclear about the time table, lack of contingent communication, and the handling of technical problems. The better organization and the shift from the transfer of learning to discovery learning confirmed the Self-regulation Theory of Deci & Ryan (1985). The findings showed that the new designs impacted the interests of the urban planning theories due to more autonomy through exercises like data collection, more feedback through online knowledge exchange with peers and the lecturer, and more relatedness between the students through cooperative learning tasks. Moreover, the multimodal learning tasks that required visual and tactile sensing and the multimedia designs that allowed the knowledge construction by sight and hearing fostered the affective domain of the learning process. Finally, the experiences were positively influenced by debriefing activities with analysis of the personal movement trajectories. The visualization assisted in the recalling of distinct moments and stimulated, for instance, a discussion about insights on how individual groups perceived and understood the questioned buildings at distinct locations.

A systematic analysis of the affective impact on LBML was carried out in the preliminary study (Chapter 3) and the main study (Chapter 4). Both studies' results revealed that the self-assessed motivation and attitude for the learning subject were narrowly satisfactory after the experiment. However, after the exam, both decreased to a stable value with equal scores after three months and equal values compared to the baseline. This outcome reveals that the LBML activity did not have a self-perceived, sustainable effect on interest in the learning content.

5.1.3.3 Spatial reasoning aspects

The learning outcomes in spatial reasoning included analytic function skills, such as wayfinding or orientation. These skills were examined through recordings and visualizations of the learners' movement trajectories with the 2D- and 3D-Viewer of OMLETH.

The students in case study 1 were critical of the lack of a function that could continuously show the user's position on the map. This complaint was addressed in OMLETH's second version and used in case study 3, an adaption the students highly appreciated. However, orientation is a fundamental part of cognitive mapping and the learning strategies in situated learning. Furthermore, orientation is the first step in a wayfinding process (Downs & Stea, 1977). By outsourcing this cognitive process, students no longer necessarily had to match the acquired mental representations with the surrounding environment to orient themselves, thanks to the assistance of the LBML system. Outsourcing orientation potentially undermines the fostering of spatial thinking, one of this study's overall goals for using LBML. However, an advantage of orientation assistance is the reduction of cognitive load. Moreover, the students reported enhanced user experience and motivation in case study 3. To find the learning stations on the OMLETH map, spatial skills like route choice, route updating, and recognition of the learning station were required (Downs & Stea, 1977). These skills involved the learner's decision of when to press the learning station button to request access to the learning content. Therefore, the web app design decision was a tradeoff in terms of reducing a part of the cognitive mapping to improve satisfaction and motivation.

The findings of the experimental study showed that the participants had no significant problems with wayfinding (see Section 4.2.2.3). Map-reading was common knowledge, and the learning stations were usually located relatively close to each other in a familiar geographical environment. The inferential functions of spatial reasoning included the use of spatial concepts, correlation, and causation. These inner thought processes were often used as part of the problem-solving aspect of individual learning tasks and described in the teachers' lesson planning descriptions. It was the teachers who decided how the learning station's tasks were designed in terms of the complexity of spatial reasoning and spatial thinking (Anderson et al. 2001). Such designs are qualitatively described, for instance, in case study 3 (Chapter 3), where the students faced the challenge of three-dimensional thinking and reasoning with the in situ phenomena and using spatial concepts to capture spatial relations among individual buildings within a settlement in map applications. Moreover, the six experiments in the experimental study (Chapter 4) also included spatial problem-solving tasks. However, due to time limitations, no further evaluation was conducted.

5.2 Contributions and application areas

The application of LBML learning in secondary, tertiary, and vocational schools has been the primary focus of this research. Various research approaches brought insights into the respective educational sectors and the findings for the field of LBML research. Furthermore, well over 100 LBML activities - in formal and informal educational institutions - were designed and implemented using OMLETH (Sailer et al. 2018), and confirmed the results of teaching and learning of the four case studies in Chapter 3. The following section provides commentary on how this dissertation contributes to LBML research.

5.2.1 An LBML system for project-based learning designs

The LBML system, in this study, is composed of modern GIS functionalities. These functionalities allow users to create, play, and review LBML activities across disciplines. The modular cloud-based system contained multimedia capabilities and interfaces to connect external services. The key technological features, stemming from this system, were identified as the most compelling technological requirements for LBML. This fact was recognized using research-based design, which was applied during the four case studies (detailed in Chapter 3). The most significant technological features – and their contribution to this study and beyond - are summarized in Table 4.

The development and evaluation of the teacher interface used throughout the case studies provided the following three main contributions:

- GIS functionalities allowed the representation of the learning stations as points and polygons. This development enabled teachers to create sophisticated designs of learning stations that are adapted to the physical context.
- The introduction of co-authoring and sharing capabilities of learning modules in Section 3.3.3.1.2 improved the quality of teaching preparation of LBML activities.
- The interoperability with external systems gave teachers the scope to construct creative designs and enhance the introduction and learnability of LBML as a new teaching strategy. By adopting this approach, it was not necessary to create new educational environments for communication and content production for teachers and schools who have already set up their own digital learning environments.

The development and evaluation of learner interface that occurred through the research conducted during the case studies provided the following insights:

- The position accuracy and speed display gave learners immediate feedback about the status of the location issues. This feedback improved the handling of cases with poor reception of location information and resulted in better user experience.

The reviewer interface provided the following insight through the research (Chapter 3) and the experiments (Chapter 4):

- The map-based visual analytics framework was introduced as a novel approach for monitoring and evaluating the learning process in case study 2. The application of this framework demonstrated the potential to extend the classroom-debriefings to data-driven classroom analyzing sessions.

The LBML system, or the individual components, can be employed - without modification - in future work on LBML research beyond the outdoor learning part. It can also be utilized - as a form of insight - in the development of future LBML systems.

5.2.2 Holistic literacy skillset for teaching

The four case studies and the empirical experiment provided insights into how teachers planned, prepared, and implemented LBML activities in the context of real instructional scenarios. The following points have emerged as the primary contributions to understanding and implementing best practices when teaching LBML:

Five common steps were identified as guidelines for planning and preparing LBML activities (see Section 4.3.1.2). They included requirements analysis, location analysis, on-site inspection, activity development, and virtual or real testing. The research demonstrated that the workload for preparing an LBML activity of two hours was similar to the preparation time for traditional field trips, but was at least twice as long as required for preparing regular classroom activities. On-site inspections by teachers consumed the majority of lesson preparation time. However, such inspections were recognized as essential for the teacher to understand the holistic context of the learning environment and, thereby, plan and prepare an authentic activity.

A set of skills were recognized and noted in the experience reports of the university lecturer (see Section 3.3.1.2 and Section 3.3.2.2) and the secondary school teachers (see Chapter 4) as necessary to effectively teach LBML (see Section 5.1.2.3). The implementation of this skill-set in teacher programs will actively enhance teacher education. Once such teacher training is implemented, LBML will undoubtedly emerge in schools and university education, similar to learning management systems two decades ago or cloud-based productivity tools in the last decade.

5.2.3 Successful cognitive and spatial cognitive learning

The evaluations conducted within the scope of this dissertation show that location-based learning, with learning tasks distributed over interactive maps, fosters both cognitive and spatial-cognitive learning outcomes. This finding, and specifically how each learning outcome contributes to research on the pedagogy of LBML, geolearning, and situated learning, is discussed in detail below:

The cognitive domain:

Regarding an overarching view on the cognitive learning outcome, case study 1 has shown that students rated ‘very positively’ the teaching approach of regularly alternating classroom learning between indoor and outdoor settings. But also one LBML activity within a whole teaching sequence of several weeks led to significantly positive results in the examination outcome, as shown in the experimental study.

In relation to the LBML activity, this research proposes three aspects in terms of positive cognitive learning outcomes.

- First, the need for proper instruction to LBML learners, in particular novice learners, to reduce the cognitive, technological, and psychological novelties of an LBML activity to cognitively benefit in the learning activity. This was particularly evident in case study 1 (see Section 3.3.1.2), where the instruction of the first course ultimately failed.
- Second, an effective teaching model must encompass a diverse approach in both the representation of the learning content, the method used and the level of learner's agency. The reduced pedagogical diversity as shown in case study 1 with 12 learning stations consisting of multiple-choice questions leads to reduced motivation and attitudes towards the learning content over time (see Section 3.3.1.2). This has changed with the case study 3 when the teaching approach was based on multimodal learning (using hands to map an object) and diversity in teaching strategies (instruction, web and field research, note-taking, data-collection, evaluations etc.) (see Section 3.3.2.2). Beromünster's experiment showed evidence of a significant cognitive learning outcome in learning environment of high agency (searching for procedures and solutions) (see Section 4.2.1.1.1).
- Third, an effective teaching model must recognize the importance of the debriefing of an LBML activity and ensure it is implemented. The teaching sequence in this study showed that such a debriefing is essential, and in doing so, confirmed Dewey's' (1910) theory about experience and reflective thinking.

Further insight resulting from the experimental study demonstrates that the LBML activity, in the long-term, neither affected the cognitive self-assessment nor the affective outcome, including motivation and attitude.

The spatial-cognitive domain: The case study 3 and the experimental study demonstrate the relevance and importance of LBML to foster spatial competencies. In particular, the map-centered approach of the student application OMLETH-Player fostered spatial understanding through map reading, orientation, and navigation to locate the learning stations. Moreover, spatial thinking skills were promoted through a variety of modes of representation. The enactive mode of representation involved the multimodal interactions through the change of visual and haptic exploration. The iconic mode of representation was applied in learning tasks that included the comparison of the mobile map and the user's surroundings or a comparison of two map situations and the surroundings, as presented in case study 3 (see Figure 18). Symbolic mode of representation was needed through the use of spatial language. Written language was used to describe a spatial phenomenon, such as was demonstrated in the location-based online debate of case study 3 (see Section 3.3.2.2.2). Oral spatial language was needed during conversation within a group to find a next learning station or tackle spatial reasoning tasks. The introduction of map-based visual analytics in the debriefings of LBML activities demonstrated a valuable extension of fostering spatial thinking. This approach resolved open issues or corrected remaining misconceptions and allowed for the use of spatial language, concept, and understanding while analyzing movement trajectories and discussing special experiences.

5.3 Limitations

The limitations of the case studies and the main study were discussed in Sections 3.4 and 4.3.2, respectively. This section provides a more holistic view of the limitations.

5.3.1 Representativeness of the samples

The first limitation of this research concerns the representativeness of the study samples. The willingness of teachers to invest several hours of work to conduct a technology-enhanced double lesson. In the experimental study, 25 of the more than 100 personally contacted teachers showed an interest in participating in the study. However, when the expected workload for planning the LBML-activity was communicated at the opening meeting, 19 of the 25 interested teachers withdrew from the study. Therefore, the teachers who participated in the study may not be representative of the teacher population in Swiss Matura schools. In fact, the six teachers, who completed the entire study, were highly motivated and engaged in learning about new teaching approaches enhanced with technologies. However, participation for students was obligatory and the selection of the students was therefore random, which is why the sample of the young people is more likely to represent the Swiss population of Matura school students. Furthermore, mobile devices have become an obsession for many young people, resulting in an ambivalent relationship as a result of the negative consequences (e.g., fear of missing out, loneliness, social anxiety, addiction, and sexting), why only a small number of participants in the experimental study explicitly mentioned the enjoyment aspect of the mobile phones. On the contrary, some students explicitly mentioned that they prefer school education without mobile phone use because they wanted to separate private and school life entirely. Similar aversions to the smartphone in the educational context have been made in the case studies 1 and 3 with university students (see Section 3.3.1.2 and Section 3.3.2.2). Some of the university students reported that they prefer teacher-guided excursions instead of technology-guided ones. This preference was attributed to the students' partiality for direct conversation with the teacher instead of through a messaging app.

5.3.2 Measuring learning outcomes

The second limitation of this research concerns the validity of measuring learning outcomes. The learning objectives of the case study 4 (see Section 4.1.3) and the experimental study involved subject-based skills, spatial abilities, and soft skills. The assessment of subject-based knowledge and skills by means of grades is still standard practice in Switzerland despite informal discussions in pedagogical communities criticizing numerical grades as insufficient or even harmful for assessing the learning process. The self-assessed cognitive and affective outcomes, including qualitative measures with coded scales and open answer questions, had limitations and were discussed in Section 4.3.2. In addition, the studies were also concerned with the measurement of the ability to recall learning experiences, including the content and spatial context, to gain insights into the situatedness of learning experiences in the long-term. The recall ability was self-assessed through qualitative surveys and revealed ambiguous results. The majority of the "a part" statements only meant that the students could still remember some of the learning stations without having to make a statement about the quantity or learning content of the stations. It demonstrated the weakness of the questionnaire's design to make valid conclusions on memory abilities (see Section 4.3.1.5). Therefore, the research could not gain quantitative insights into the efficacy of LBML in terms of knowledge construction in the episodic memory. To overcome this limitation and to employ the externalization of semantic and episodic knowledge construction processes as abstract representations, Schnotz (2006) suggested producing mind maps, two-dimensional diagrams, flowcharts, and tree diagrams. Furthermore, concept maps are considered essential metacognitive learning strategies for reasoning and understanding. The Gardony Map Drawing Analyzer[37] (Gardony et al., 2016) is suggested as an effective tool for assessing spatial memory. A graphical user interface permits rapid computational sketch map analysis based on pairwise comparisons between landmarks, as well as bidimensional regression parameters, which together reflect sketch map quality at two levels: survey knowledge and landmark knowledge. The survey measures assess

[37] http://www.aarongardony.com/tools/map-drawing-analyzer (01.01.2020)

the overall landmark configuration and provide a whole-map analysis. To address map-reading skills and environmental spatial abilities, a standardized survey, such as the Santa Barbara Sense of Direction (SBSOD) self-report scale, could have been employed.

5.3.3 Hardware and software

Mobile phone literacy

The third limitation concerns the understanding of mobile phones. It was assumed that the participants' familiarity with mobile phones would ensure the absence of any technological novelty effect as an extraneous variable. The questionnaire results of the experimental study confirmed this (see Section 4.3.1.2). However, across all studies, the direct observations during the introduction of OMLETH showed some limitations in the participants' technical understanding with mobile phones. Challenges included configuring the location-sharing feature, especially for iPhone users, and dealing with mobile data, battery use, GPS positioning, and browser handling before and after execution. Furthermore, some of to students reported that it confused them when browsing through the different browser tabs to use OMLETH's external services and mentioned that they generally avoid browser applications that force them to use user credentials. However, due to privacy, authentication was mandatory with OMLETH.

5.3.4 Data privacy

One of the top concerns of learning scientists of online user-generated content is data privacy. Mobile learning research studies are increasingly being conducted in fully cloud-based systems and context-aware computing, justifying this privacy concern.

The work presented in this dissertation contains partly precise measurements of personal decisions and can be used to expose the participants' activity behaviors. For instance, the learners' movement trajectories can reveal forbidden or dangerous actions, such as crossing a busy road or trespassing on private property. The average walking speed could, for example, indicate the state of the user's health. This study, consciously, did not collect any non-relevant information from participants' movements. However, some large enterprises in EdTech, representing a broad category of educational products and services, are attempting to collect as much contextual data as possible to benefit future jobs and literacy predictions (Peterson, 2016). This direction in data collection potentially exposes students to the risk of discrimination (Regan & Bailey, 2019). With data mining techniques, it is possible to identify real persons based on their trajectories (Krumm, 2009), even if the user is anonymized (Bettini et al. 2005). In their study on geoprivacy, Keßler and McKenzie (2018) reflected on the issue of personal location data exposing personal, identifiable information. They argued that location information is different from other kinds of information and is particularly worthy of protection. Supporting this argument for more heightened protection of the participants, the study procedure of this research purposely took the following steps: anonymized data using pseudonyms; informed users what data processing would be carried out; guaranteed an adequate level of protection through the systems architecture; and, deleted the user data after teachers made a backup and no longer needed the data online.

Positive effects of the data privacy issue

However, the issue of data privacy also had positive effects throughout the study. Data privacy was mostly a side-topic and metacognitive part of the activities' debriefings. The visualization of the high-resolution movement data always first surprised the students, prompted discussions, and sensitized the students to the handling of web-based applications and the sharing of personal data. This side effect was referenced in Keßler and McKenzie's (2018) study, who propagated for more in-depth training and education for students, on the subject of position tracking and location-based services. Knowledge about geoprivacy allows people to make more informed decisions about the tools and services they use. Also, with empowered users, a push for more restrictive legislation and compulsion of service providers to be more transparent about their data collection and use policies can be realized. The discussion in this dissertation on data-privacy in the LBML context and the location-sharing geoprivacy issue has led to the recognition of a need for student-friendly information on EdTech platforms. A transparent data collection strategy, for example, in the form of a traffic light system (red: no data is collected; yellow: in the GTC explained data for certain action; green: an unknown amount and type of data is collected) would help to indicate, in a simple and transparent way, which data can be used for the system for a certain feature in context-based applications.

6 Future Work

Drawing on the findings of this study, and the broader discussions and the observations stemming from it, this chapter presents recommendations and directions for further research. After general thoughts in the first Section 6.1, Section 6.2 elaborates on how LBML can be used in project-based learning scenarios to benefit the creative work in which teachers engage when preparing LBML designs. Section 6.3 describes the next steps in learning from user data (i.e., movement trajectories), collected during the activities. Finally, Section 6.4 ideates future applications of LBML with mixed reality and head-mounted displays.

6.1 General thoughts

Teachers in this study had experiences ranging from no ICT skills to advanced ICT and GIS competencies. Designing LBML requires teachers to have a holistic set of skills and literacies, including ICT skills, spatial cognitive skills, creativity, pedagogical sensitivity about the differences between teacher-centered, and learner-centered pedagogy (Sailer et al. 2015). Thus, to foster the deployment of mobile learning or LBML in real educational settings, it has to be integrated into teacher education and training. Baran (2014) presented with teacher training about mobile learning and teacher training with mobile learning two general approaches for integrating mobile learning into teacher education. Hall & Connolly (2019) suggested exemplars of concepts, methodologies, and systematic approaches to the design, deployment, and evaluation of mobile learning for teacher educators.

As for student participants, some mentioned a positive attitude towards traditional learning approaches without technology, in particular good students in terms of examination outcome. According to the corresponding teachers, this was attributed to the fact that they possess successful learning strategies that are geared toward efficiency and success in traditional contexts. In future research, teaching sequences including more in-depth introductions of the methodology with related educational topics such as situated learning, sustainable learning, and seamless learning, and related technological topics such as data literacy, sensor literacy, cloud computing, and privacy could help provide a better understanding and acceptance of mobile learning in educational settings.

These general thoughts and conclusions on teaching relate to the subject of the current study and the situation in the Swiss school context (see also Section 5.1.2.3) and differ in comparison to other countries. A possible approach to address the issues outlined above (i.e., teacher skill requirements and teaching strategies) is to teach students to create LBML lessons themselves (see next section), thereby allowing teachers to learn and acquire the skills discussed in co-construction with students.

6.2 Design your own LBML project

The experience reports of the planning and preparation of LBML activities in the cases studies 1, 3, and 4 and the six OMLETH designs of the experimental study show that there is enormous potential for improving spatial thinking skills in designing an LBML activity. This finding was likewise witnessed in Edmonds and Smith's (2017) empirical study on mobile GIS, in which the teaching model of learning by designing was employed. In the study, university students enrolled in a core undergraduate course (Business and Society), designed and developed prototype games as an educational activity to explore pedagogical strategies in personalized learning. Students were required to think of themselves as tour operators who needed to develop a new tourism product. The key task was to design and develop a prototype LBML game for a destination of their choice. This guided inquiry, based on Tan et al.'s (2018) taxonomy, allowed the students to initiate the problem, design the procedure, and arrive at a solution. The students were introduced to the topic by playing a local LBML game. They were then instructed to deconstruct the game's design and development into individual components. The students were instructed how to create LBML games using a distinct LBML system before they formed small teams, chose a topic, and began storyboarding the concept, narratives, places, media, interactivity, and gameplay in a provided template. They designed and developed their own game with ongoing email support throughout the process. In Bloom's Taxonomy (see Fig. 5), designing is regarded as the highest level of the cognitive dimension. Edmonds and Smith's (2017) approach demonstrated that both the playing and self-designing of LBML games could deliver active, engaging, and authentic educational experiences and foster skills, such as the learner-centered inquiry of new theories (e.g., game theories in the example), while developing new ICT skills. A similar outcome regarding engagement occurred in an explorative study with a summer youth program[38] of pupils ranging from 11 to 14 years of age who designed their own LBML activities.

The provision of a game template, and a distinct LBML game platform, afforded some structure in Edmonds and Smith's (2017) inquiry approach. In future research, one could go one step further and launch a nation-wide GEOChallenge[39] as a citizen-science project for primary and secondary school pupils, in which students would create location-based mobile games on their own. The intended project does not have any prerequisites in terms of the topic, design structure, or technology. The goal of this explorative research is to understand how pupils ranging from 13 to 17 years of age use their ICT skills and spatial abilities and select technologies and data to master the challenge. A pre-survey with 40 pupils in the target group revealed that they felt eager to participate in such research. The prospects seemed promising, and the campaign was launched in late 2019, inviting the geography teachers who participated in this study (see Chapter 4). However, the teachers' feedback was disappointing. The teachers reported that they were concerned about the expected workload to guide the students and that such a project would distract from the current curricula. The teachers' lack of capacity and confidence to use technology innovatively and effectively was representative of the insights gained in this dissertation (see Section 5.3.1). Due to this and the coronavirus outbreak in early 2020, this project has been postponed to 2021. The study will be redesigned, and the project description reformulated for another attempt in the future. Despite this setback in proceeding with this proposed research, the presented examples with the model *learning by designing,* are a promising future direction for improving LBML in terms of experimental and sustainable learning.

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38 https://ferienplausch.feriennet.projuventute.ch/activity/abenteuer-in-zuerich (01.01.2020),

39 http://geoschoolday.ch/ (01.01.2020)

6.3 LBML analytics on cognitive and affective learning outcomes

Two main reasons guided this study's focus on real-time data-processing and map-based visual analytics. First, the study sought to use feedback about the positioning accuracy of the students' mobile phones or students' wayfinding issues during the activity in real-time to immediately help individual pupils to cope with the situation on-site. Second, the study sought to conduct a data-driven evaluation in the in-class debriefing and in the student's self-evaluations to gain insight on specific occurrences during the activity and deepen the discussion.

A further aim along this study was to develop a framework that allowed for detecting patterns on the affective learning outcome such as motivation and engagement in the movement data of mobile learners, thus avoiding traditional interventions that could disrupt the learning process with surveys and other data collections during the activities. In connection with a master thesis, such a framework (and the research question behind it) emerged in Graf et. al's (2018) empirical study on the movement of hikers in a tourist area. The hikers' route contained learning tasks about regional characteristics. The content design was based on educational theories that aimed to generate a high level of motivation and activate the hikers' engagement. The hikers used their mobile phones and the OMLETH system, along with an external GPS receiver, which collected data in 1-second intervals. To ascertain the participants' motivation, the Instructional Material Motivational Survey (IMMS), based on Keller's (1999) ARCS model, was used. The collected trajectory data from the two sources, the OMLETH-Player position tracking, and an external GPS receiver, were analyzed for relationships concerning the following movement patterns: turn-around, extended-walk, extended-stop, and interrupted-walk. The results revealed no correlation between the computed movement parameters and motivation levels due to poor reception of GPS respectively poor positional accuracy. Subsequently, gaps rendered the data quality inadequate (Graf et al., 2018). The reasons for the poor GPS quality were presumably due to the route of the LBML trail just below a mountain slope in a predominantly forested area.

To address the problem of tracking motivation through movement trajectories, future research could draw on the research of Multimodal Learning Analytics (MMLA) (Worsley & Blikstein, 2011), and multi-modal sensory input approaches beyond GPS. For instance, to enhance the tactile position-sensor, data from other sensors built into the mobile phone (i.e., the accelerometer data) or visual sensing measurements (i.e., gaze-based interaction data for wayfinding) can be used (Giannopoulos, 2016). Furthermore, according to Sharples et al. (2007), a central feature of the LBML experience in groups that encourages motivation and a positive attitude towards the learning content is the conversation, the negotiation of differences and the understanding of each other's experiences. Therefore, the auditory reception of oral communications within a group of learners, combined with records of digital communication via the messaging app, could offer novel insights into the cognitive and affective learning process of LBML. Regarding MMLA, Worsley et al. (2016) took this one step further. They suggested the use of audio transcripts in combination with bio-physiological data to provide insight into the emotional state of a learner. Regarding environmental context analytics, Sailer et al., (2019) introduced a framework to automatically analyze the runners' movement trajectories under the consideration of the slope and a wide range of vegetation types. Worsley et al.'s and Sailer et al.'s approach in combination is a promising approach for future work to improve the understanding of the learning process in LBML.

6.4 LBML with mixed reality on head-mounted displays

The case study 1 demonstrated that mobile phones had hardware limitations for immersive learning and situational awareness. The following issues were identified in relation to map interaction and augmented reality (AR) on mobile phones:

- The first point leads with **insufficient screen sizes** that limited reading text, scrolling through images, and studying maps during wayfinding or spatial reasoning tasks, as well as further technological limitations such as **screen reflection** (Christian Sailer, Schito, et al., 2015).
- The second point addresses the **field of view** for AR applications. The image plane depends on the camera's field of view (FOV). The viewing frustum of mobile phones is, by default, narrow (vertical to horizontal: 50 to 70 degrees), and it is, therefore, challenging to register the physical surrounding. Humans are naturally accustomed to a FOV of slightly over 210 degrees (Traquair, 1927). As a result, users constantly move the hand-held device to explore the surroundings, impairing their immersion.
- The third point refers to the issue of **Human-computer interaction** which is limited on mobile phones due to their less interactive nature. To be a productive work tool, mobile phones need to be able to create and send long text messages, write location-based narratives, etc. However, the HCI of contemporary mobile phones is limited in naturalistic, tactile interactions such that is found on a computer or laptop keyboard, or with a computer mouse. Contemporary phones often have on-screen

> keyboards, which impede the already limited screen space available for most mobile devices. Therefore, the content and interaction complexity of services and applications was adapted to the reduced capabilities of the mobile device, which also affects the content produced. One consequence of this is microblogging, known primarily from social media applications such as Twitter, which has adapted to the technology and changed the way information is delivered (Döring, 2014).

Meanwhile, technological developments have significantly improved the capabilities and the mobility of head-mounted displays (HMD). These advancements have enabled a significantly better immersion with multi-sensory stimuli, increased the devices' popularity, and affected numerous fields of research and development (Pierdicca, Frontoni, Pollini, Trani, & Verdini, 2017). Current generations of HMDs are bulky and cumbersome to wear in pervasive scenarios such as mobile learning. However, future displays (frequently referred to as data glasses), will likely be lighter, have larger naturally-sized fields-of-view, and will augment real-world settings with better rendering performance than the current hardware generation. These improvements will redefine the standing of mixed reality in the economy and society.

There is considerable potential for interdisciplinary research amongst computer scientists, engineers, and pedagogues on tailoring AR experiences on HMDs for mobile learning. Novel ways of multimodal and interactive learning, and interaction between peers, are suggested by Sailer et al. (2019) and extended through the following ideas:

Visualization of learning content

As far as the visualization of learning content is concerned, the content can be presented in different modes, which determine the complexity of the inquiry-based learning process. A photorealistic content, which is seamlessly integrated into the real world, allows different teaching strategies such as simulations, game-based, or role-play learning in fully immersive experiences. Abstracted information, such as geographical data, could be georeferenced as seen with location-based AR or statistical data. Furthermore, textual information about objects could be referenced as graphs or informational panels in distinct places on the AR display.

Human-computer and human-human interactions

Regarding human-computer and human-human interactions, existing techniques based on gestures, voice commands, or tangible controllers might be extendable to improve the mobile learning experience. Furthermore, alternative input modalities, such as eye-tracking, seem promising as a way to identify parts of the environment that could be adjusted to tailor the AR experience to the interests of the user (Kwok & Kiefer, 2019).

Conversational, collaborative, and cooperative learning

Conversations, collaborations, and cooperation can be technologically-enhanced through close or remote collaboration approaches. Conversations, such as face-to-face interactions, can be redefined by a screen extension, where personal work can be presented and shared at a realistic size. Remote conversations and collaborations between people virtually in situ, but physically remote, can be redefined in AR via holographic telepresence of the near spatial environment in photorealistic 3D and the peer learners.

Assuming the existence of such technologies, these immersive displays will introduce a new world of didactical opportunities and novel context-aware designs for seamless mobile learning, particularly in outdoor learning environments. Applications include the following:

- Situated inquiry can be immersed in the past (e.g., to view a river city 200 years ago) or in futuristic environments (e.g., to teach urban planning) as real-world renderings.
- Geospatial analysis can be implemented, for example, as shadow calculations in the urban planning context or noise modeling in the traffic planning context, or forbidden areas and space trough visual and dynamic geofencing.
- Geospatial modeling can be implemented, for example, for modeling of physical or abstract concepts such as 3D objects in AR.
- Gaze-based interactions allow for hands-free interactions, and natural gesture interactions can be computed for such purposes as naturalistic data collection.

In sum, with the help of AR displays and a variety of communication types, visualization, simulation, and interaction techniques inspired by GIS, learners immersed in new contexts will benefit from better responsiveness built in the system, which more suitably caters to their needs. Learning designs could include tasks of reconstructing the past world or ancient phenomena, or creating future scenarios, models, and visions directly on-site in the learner’s surroundings, as Google StreetView does on their 2D and 3D maps. To implement and evaluate such educational scenarios, appropriate technology, and empirical research will be required. In particular, future research should involve the identification of which principles are sound in AR displays known from state-of-the-art MR, LBML, or GIS approaches and where new concepts will be necessary to foster location-based mobile learning in the age of “homo mixed reality”.

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Appendix

I. Selected educational factors of learning performance

The research of John Hattie generated great interest when he published in Visible Learning the relationship of educational factors and student performance[40] based on a synthesis of 800 meta-analyses in Hattie (2013) and based on 1200 meta-analyses in Hattie (2015). Hattie used the statistical measure effect size (Cohen's d) to gather the influence of educational factors on educational outcomes. The effect size can be quantitatively measured by the standardized mean difference between the two groups. Based on Hattie (2013) teacher effects are medium effects between 0.2 and 0.4 and the zone of desired effect sizes are $d > 0.40$. For example, class size is with (d =0.21) a typical teacher effect, while peer tutoring (d=0.55) or immediate feedback (success/failure) (d= 1.13) are in the zone of desired effects. The latest ranking consists of 252 influences, that includes some technology-related strategies such as

- web-based learning (d=0.18),
- technology in small groups (d=0.21),
- audio-visual methods (0.22),
- inquiry-based teaching (d=0.31),
- gaming/simulations (d=0.35),
- mobile phones (d=0.37).

Selected learning strategies that relate location-based mobile learning are

- collaborative learning (d=0.34),
- cooperative learning (d=0.44),
- direct instruction (d=0.59),
- problem-solving teaching (d=0.61),
- feedback (d=0.73),
- formative assessment (0.9).

These results are strongly discussed from the perspective of a statistician, for example, Bergeron and Rivard (2017), due to many uncertainties in the study design, sampling, procedure, and analysis. However, we present three studies with large sample sizes that contributed to the field of location-based mobile learning.

40 https://visible-learning.org/hattie-ranking-influences-effect-sizes-learning-achievement/ (01.01.2020)

II. Survey of the experimental study

Types of closed responses

5 items Likert-scale		3 item scale	
Disagree Strongly (2)	trifft gar nicht zu (2)	yes	ja
Disagree (3)	trifft wenig zu (3)	a part	nur ein Teil
Agree Slightly (4)	trifft genügend zu (4)	nothing	nein, keine Ahnung
Agree (5)	trifft gut zu (5)		
Agree Strongly (6)	trifft perfekt zu (6)		

Questionnaire (Q1) - Tour survey

Research Question	Survey question	Type of response
RQ4.4	Q1.1: My understanding: Thanks to the learning module, I understood the topic better than if I had dealt with it only in the classroom.	Five-item Likert scale
	Q1.2: My motivation: Thanks to the learning module, my motivation on the topic is now higher than if I had dealt with it only in the classroom.	
	Q1.3: My attitude: Through the learning module, I will, in the future, be more committed to the topic than if I had dealt with it only in the classroom.	
RQ4.2	Q1.4: Positioning: The positioning in OMLETH worked in a satisfying way to access the learning elements.	Five-item Likert scale
	Q1.5: Internet access: The online maps and learning elements in OMLETH were good enough to access this information.	
	Q1.6: OMLETH operated at a stable level.	
RQ4.4	Q1.7: In general, the OMLETH approach added value compared to classroom instruction.	Five-item Likert scale
RQ4.2	Q1.8: Remarks about weather, disruption, special experiences:	Open answer

Questionnaire (Q1) - Tour survey in German

Research Question	Survey question
RQ4.4	Q1.1: Mein Verständnis: „Durch den Lernparcours habe ich das Thema besser verstanden, als wenn ich dieses nur im Klassenzimmer behandelt hätte.
	Q1.2: Meine Motivation: „Durch den Lernparcours ist jetzt meine Motivation zum Thema höher, als wenn ich dieses nur im Klassenzimmer behandelt hätte.
	Q1.3: Meine Haltung: „Durch den Lernparcours werde ich mich in Zukunft mehr für das Thema einsetzen, als wenn ich dieses nur im Klassenzimmer behandelt hätte.
RQ4.2	Q1.4: Positionierung: „Die Positionierung in OMLETH funktionierte befriedigend, um auf die Lernelemente zugreifen zu können.
	Q1.5: Internetzugang: „Die Online-Karten und Lernelemente in OMLETH erschienen befriedigend, um auf diese Informationen zugreifen zu können.
	Q1.6: OMLETH funktionierte stabil.
RQ4.4	Q1.7: Generell empfand ich den Ansatz von OMLETH als Mehrwert gegenüber geführten Lektionen im Klassenzimmer.
RQ4.2	Q1.8: Allgemeine Bemerkungen zu Wetter, Störungen und speziellen Ereignissen.

Questionnaire (Q2) - Examination survey

Research Question	Survey question	Type of response
RQ4.4	Q2.1: I enjoyed the module.	Five-item Likert scale
	Q2.2: I enjoyed learning on my mobile phone.	
	Q2.3: The learning approach of the tour is innovative.	
RQ4.5	Q2.4: I could explain the content of all the learning stations completed on the tour.	Three-item scale
RQ4.4	Q2.5: The experiences and lessons learned on the tour were supportive of learning for the examination.	Five-item Likert scale
	Q2.6: The module increased my motivation to learn for the examination.	
	Q2.7: Remarks about the tour:	Open answer
RQ4.4	Q2.81: My understanding: I currently understand the topic well.	Five-item Likert scale
	Q2.82: My motivation: My motivation for the subject is basically good at the moment.	
	Q2.83: My attitude: In the future, I would like to commit myself more strongly to the topic.	
	Q2.9: Remarks about my self-assessment:	Open answer

Questionnaire (Q2) - Examination survey in German

Research Question	Survey question
RQ4.4	Q2.1: Der Parcours machte mir Spass.
	Q2.2: Das Lernen am Smartphone machte mir Spass.
	Q2.3: Das Lernen in Form des Parcours fand ich innovativ..
RQ4.5	Q2.4: Ich könnte heute alle absolvierten Postenthemen des Parcours noch aufzählen..
RQ4.4	Q2.5: Die Erfahrungen und Erlebnisse vom Parcours wirkten unterstützend beim Lernen auf die Prüfung.
	Q2.6: Der Parcours steigerte meine Motivation auf die Prüfung zu lernen.
	Q2.7: Persönliche Bemerkungen zum Parcours
RQ4.4	Q2.81: Mein Verständnis: „Das Thema habe ich zum heutigen Zeitpunkt grundsätzlich gut verstanden.
	Q2.82: Meine Motivation: „Meine Motivation zum Thema ist zum heutigen Zeitpunkt grundsätzlich gut.
	Q2.83: Meine Haltung: „In Zukunft möchte ich mich grundsätzlich mehr für das Thema einsetzen.
	Q2.9: Persönliche Bemerkungen zu meiner Beurteilung

Questionnaire (Q3) - Long-term survey

Research Question	Survey question	Type of response
RQ4.4	Q3.1: School subject: Basically, I have a positive attitude towards this school subject.	Five-item Likert scale
	Q3.2: My interest before the first school lesson: My interest in the topic before the first lesson was good.	
RQ4.5	Q3.31: I could explain the content of all the learning stations completed on the tour.	Three items scale
	Q3.32: The experiences from the tour are helpful for my expertise on the topic.	Five-item Likert scale
	Q3.33: If I were to meet the learning content of the module again with a concrete example, I would immediately think of the module itself.	
RQ4.4	Q3.4: I would like to elaborate on a topic once again with location-based examples and my own smartphone.	Five-item Likert scale
	Q3.51: If the examination were also designed as such a module, I would actively explore similar examples in everyday life.	
	Q3.52: If the examination were also designed as such a module, I would repeat the learning module.	
RQ4.4	Q3.60: My understanding: I understand the topic well at this point in time.	Five-item Likert scale
	Q3.61: My motivation: My motivation for the subject is good at the moment.	
	Q3.63: My attitude: In the future, I would like to commit myself more strongly to the topic.	
	Q3.64: Closing remarks:	Open answers

Questionnaire (Q3) - Long-term survey in German

Research Question	Survey question
RQ4.4	Q3.1: Schulfach: Grundsätzlich bin ich positiv auf dieses Schulfach eingestellt.
	Q3.2: Mein Interesse vor der ersten Schullektion: Meine Interesse zum Thema vor der ersten Lektion war grundsätzlich gut.
RQ4.5	Q3.31: Ich könnte heute alle absolvierten Postenthemen des Parcours noch aufzählen.
	Q3.32: Die Erlebnisse vom Parcours wirken unterstützend für meine Fachkenntnis zum Thema heute.
	Q3.33: Wenn ich die Lerninhalte des Parcours an einem konkreten Beispiel wieder antreffen würde, denke ich sofort gerade an den Parcours.
RQ4.4	Q3.4: Ich würde gerne wieder einmal ein Thema erarbeiten mit konkreten Beispielen vor Ort und dem eigenen Smartphone.
	Q3.51: Wenn die Prüfung ebenfalls als ein solcher Parcours konzipiert wäre, würde ich mich aktiv im Alltag nach ähnlichen Beispielen erkunden.

	Q3.52: Wenn die Prüfung ebenfalls als ein solcher Parcours konzipiert wäre, würde ich den Lernparcours wiederholen.
RQ4.4	Q3.10: Mein Verständnis: Das Thema habe ich zum heutigen Zeitpunkt grundsätzlich gut verstanden.
	Q3.11: Meine Motivation heute: „Meine Motivation zum Thema ist zum heutigen Zeitpunkt grundsätzlich gut.
	Q3.13: Meine Haltung: „In Zukunft möchte ich mich grundsätzlich mehr für das Thema einsetzen.
	Q3.14: Meine abschliessenden Bemerkungen

III. Semi-structured interview with the teachers

A Lernparcours Überblick

Ort: ....

Datum: .... **Zeitpunkt**: ....

Thema: ....

Dauer: .... **Konzeption** (nach Reihenfolge oder frei): ....

Wetter: .... **Temperatur**: .....°C

Weitere Beschreibung des Kontexts: ......

OMLETH:

Modulname: .... ID: ... Code: ...... Editor: ....

Nutzerdaten:

Anzahl Nutzende: ..... in .... Gruppen à .. Lernende
Anzahl Anfragen Lernstationen, ... Anzahl Trajektorien: ....

Kartenansicht der Studententrajektoren

B Resultate der Selbstbeurteilungsresultate der SchülerInnen

Besprechung der Prfüungsresultate und Umfragen auf Grundlage Bar Plots und deskriptiver Statistik

C Planung und Gestaltung des Lernparcours

Planung

Dieser Aspekt interessiert wie die Parcours-Lektion geplant und gestaltet wurde. Teamteaching?

1.Planungsschritte:

Was waren die konkreten Planungsschritte und dessen Arbeitsaufwand?

Mögliche Antworten: Reko, Recherche, Skizzieren, Test oder Skizzieren, Reko, Testen

2.Materialsammlung:

Wie wurde das Material gesucht und zusammengestellt (inhaltliche, didaktische und mediale Analyse). In welcher Form (digital, analog)? Gab es Vorstrukturen?

Mögliche Antworten: lehrplanorientiert, lernzielorientiert, eigene professionelle Erfahrung, Vorwissen, Kollegenbefragung, Spontanrecherche im Internet, Vorort-Reko

3.Verräumlichung:

Wie wurden die Lerneinheiten (Instruktionen und Aufgaben) verräumlicht?

Mögliche Antworten: OMLETH Map, Google Map, Rechercheerfahrung (Reko), Alltagswissen

4.Testing:

Wie, wann und mit wem wurde der Parcours getestet? Wurde einmal oder mehrmals getestet?

Mögliche Antworten:

Gar nicht, Als Einzelperson, Zu Zweit, Durch dritte, Weitere Möglichkeiten

Gestaltung

Dieser Aspekt beinhaltet die Fragen, welche Lerneinheiten durch welche Lernmethoden zu welchem Zeitpunkt (Verlauf) umgesetzt wurden und welche digitalen Medien berücksichtigt wurden.

Lehrerfahrung:

Was sind die Lehrerfahrungen und Erlebnisse ausserschulisches Lernen? Welche Ansätze und Konzept haben funktioniert oder sind wichtig für ausserschulisches Lernen?

Was sind die Lehrerfahrungen mit digitale Technologien im Unterricht?

Kurz-Beschreibung:

Lernphasen:

Welche Lernphasen wurden gewählt? Waren es neue Lerninhalte oder wurden sie mit Aufgaben geübt? Wurde das Tool zur Zeitabschätzung benutzt?

Mögliche Antworten: Einstieg, Erarbeitung, Test, Abschluss / Sicherung

Lehrformen:

Welche Lernprozessansätze wurde wann, wo gewählt? Vermittlung (darbietend; Anleitung) oder Problemlösung (aktivierend, Eigenaktivität)? Wurde Lernprozesse kontrolliert – formativ oder summativ?

Mögliche Antworten: Instruktionen, Konstruktionen, Transferaufgaben, Lernkontrollen

Medien:

Welche analogen und digitalen Medien, Messinstrumente wurden wann, wo und wieviel benutzt?

Mögliche Antworten: Text, Bild, Audio, Video, Karte, Spiel/Simulation, Apps, Messgeräte, Analoge Methode

Christian Sailer

Curriculum Vitae

Stefano-Franscini-Platz 5, 8093 Zurich, Switzerland

Education

Doctor of Sciences, ETH Zurich, Zurich, Switzerland 2020 (expected)

Department of Civil, Environmental and Geomatic Engineering
Geoinformation Engineering
Supervisor: Prof. Dr. Martin Raubal

Master of Science, University, of Zurich, Switzerland, 2008
Geography
Thesis: *Filtering of Laser Altimetry Data using Surface-specific Filteralgorithms*
Supervisor: Prof. Dr. Robert Weibel

Matura C, MNG Rämibühl, Zürich, Switzerland 2001

Work

Education & Research Esri Schweiz AG, since 2009

Technical Sales, Esri Schweiz AG, 2006-2009

Business Surveys Analyst, KOF ETH, 2003-2006

Academic Activities

Workshop Co-Organizer of Vespucci Summer Institute 2016, Benicassim, Spain.

“Geoinformatics: Enabling open cities”

Publications

2019

Sailer, C., Rudi, D., Kurzhals, K., & Raubal, M. (2019). Towards Seamless Mobile Learning with Mixed Reality on Head-Mounted Displays. In *World Conference on Mobile and Contextual Learning*, 69-76.

Sailer, C., Martin, H., Gaia, L., & Raubal, M. (2019). Analyzing performance in Orienteering from movement trajectories and contextual information. In *15th International Conference on Location-Based Services*, 141-146..

2018

Sailer, C., Kiefer, P., & Raubal, M. (2018). OMLETH: A multimedia guide for field trips. *ETH Learning and Teaching Journal*, *1*(1).

Graf, A. B., Sailer, C., Jonietz, D., & Weibel, R. (2018). Towards Extracting Motivation from Mobile Learners' Movement Trajectories. In *Adjunct Proceedings of the 14th International Conference on Location Based Services*, 69-74. ETH Zürich.

2016

Sailer, C., Kiefer, P., Schito, J., & Raubal, M. (2016). Map-based visual analytics of moving learners. *International Journal of Mobile Human Computer Interaction (IJMHCI)*, *8*(4), 1-28.

2015

Sailer, C., Schito, J., Kiefer, P., & Raubal, M. (2015). Teachers matter: Challenges of using a location-based mobile learning platform. In *International Conference on Mobile and Contextual Learning* 239-255. Springer, Cham

Sailer, C., Kiefer, P., Schito, J., & Raubal, M. (2015). An evaluation method for location-based mobile learning based on spatio-temporal analysis of learner trajectories. In *Proceedings of the 17th International conference on human-computer Interaction with mobile devices and services Adjunct*,1212-1218

Schito, J., Sailer, C., & Kiefer, P. (2015). Bridging the gap between location-based games and teaching. In *AGILE 2015 Workshop on Geogames and Geoplay*. ETH Zürich.

Sailer, C., Kiefer, P., & Raubal, M. (2015). An Integrated Learning Management System for Location-Based Mobile Learning. *International Association for Development of the Information Society*.