Orchestrating scaffolded outdoor mobile learning activities

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Abstract

Since the beginning of time, technological innovations have formed the basis for the development of society and supported the most fundamental societal features. The educational system is no exception. This we have witnessed on many occasions, as for example in form of the transformations of learning and teaching introduced by the printing press, the calculator and computers. With the advance of mobile technology, we have received another technology that inspires research fields to study the learning and teaching potentials that mobile technology may present. It is from here this thesis takes its general starting point, namely, in the determination to critically examine the role mobile technology can play in supporting outdoor learning activities.

More specifically, the thesis attempts to, on the one hand, develop an understanding of the challenges and limitations associated with scaffolding students’ mobile learning in outdoor environments. On the other hand, based on such a developed understanding, the thesis investigates how mobile technology-supported outdoor activities should be orchestrated to scaffold students learning. Orchestration is, in this thesis, understood as the process of productively coordinating supportive interventions across multiple learning activities occurring at multiple social levels involving multiple contexts, and multiple tools and media.

The framework of design-based research has guided the methodological approach. Three design studies formed the empirical basis of the study of the issues. The results of the thesis indicate the difficulties and challenges in supporting students in outdoor contexts and delineate an understanding of how mobile outdoor learning activities can be orchestrated with students scaffolding needs taken into account.

The thesis contributes with a conceptualization of and a model for orchestration of mobile learning activities, a framework for design-based research in mobile learning, as well as a critical perspective on the introduction of mobile technology in education.
Sammanfattning


Avhandlingen riktar ett specifikt fokus mot att i första hand skapa en förståelse för de utmaningar och begränsningar som är knutna till stödjandet av elevers mobila lärande i utomhusmiljöer, och utifrån en sådan förståelse, undersöka hur mobil-teknikstödda utomhusaktiviteter bör orkestreras för att stödja elevers lärande. Orkestrering är i denna avhandling förstått som ett produktivt koordinerande av stödjande interventioner tvärs över multipla lärandeaktiviteter, multipla miljöer samt multipla sociala nivåer, inbegripet användning av multipla verktyg och multimedier.

Den metodologiska ansatsen har väglett av ramverket Design-based research. Tre designstudier har utgjort den empiriska grunden i studiet av frågeställningarna. Avhandlingens resultat pekar dels på svårigheter och utmaningar i stödjandet av elever i utomhuskontexter, och dels på en förståelse för hur mobila utomhuslärandeaktiviteter kan orkestreras för att ta elevers stödbehov i beaktande.

Avhandlingen bidrar med en konceptualisering av och en modell för orkestrerandet av mobila lärande aktiviteter, ett ramverk för Design-based research inom mobilt lärande, samt ett kritiskt perspektiv på introducerandet av mobil teknologi i undervisning.
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Chapter 1: Introduction

Technological innovations have played a significant role in the evolution of our society and people tend to expect great transformations and societal developments from them. For instance, we see the continuous production of optimistic discourses emphasizing the perceived promises of computer technologies in education. The inspiring power inherent in the expressed promises of computer technologies has encouraged the reshaping of our fundamental understanding of education; it has, in fact, encouraged us to redefine our methods of teaching and learning, reframe the way we conduct and focus educational research, alter and finance educational reforms, recast the relationship between educational systems and economic systems, and transform our beliefs about the skills required for the twenty-first century in line with the demands of tomorrow's working world (Oppenheimer, 2007).

Although the computer has long been the main technological vehicle encouraging the envisioning of these particular educational transformations, we have witnessed another wave of promises brought about by the introduction of mobile technologies. As a matter of fact, in pace with that mobile technology has become a considerably embraced cultural resource, there is, since the mid 90’s, a research field of mobile learning that makes proof of a great interest in investigating and proclaiming the promises associated with educational use of mobile technologies.

For instance, claims are made that mobile learning has the potential to transform the actual nature of learning (Traxler, 2007), but it is, however, unclear how such transformations are possible. Another common argument is that mobile learning enables learning anytime and everywhere, a rhetoric that has aptly been described as an 'omnipresent and run-of-the-mill characterization' (Frohberg et al, 2009: p.308). Learning anytime and anywhere enabled by various tools and support is nothing new; we certainly do that most of the time. Such rhetoric does not explicitly take into account what it means to understand the specific qualities of learning at a certain place and at a certain time. More importantly, it is a rhetoric that does not explicitly take into account if the suggested mobile learning activities are desired by the educational system, if they are economically feasible, aligned to educational goals, and feasible. At times, one can almost
believe that mobile learning is viewed as the ultimate solution for a declining educational system and as a replacement for existing educational practices.

Against such a background, the expected results may be part of what Cuban (1986) and Oppenheimer (2007) describe as the repetitive cycle of technology in education, characterized by hype, investment, poor integration, and lack of educational outcomes. After all, when we review the existing literature in the field of mobile learning, it seems that the field is going through similar phases, and that mobile learning and its pedagogical opportunities are sometimes glorified, indicating a possible hype phase.

In the light of the investment phase suggested by Cuban (1986), copious resources have been invested in interesting research projects conducted across various contexts with diverse target groups and exploring the role of mobile technology as support for outdoor education guided by a wide range of pedagogical traditions such as inquiry-based learning (Naismith et al, 2005a; Pachler et al, 2010). Examples of pioneer projects in the area include Savannah (Facer et al, 2004), the Ambient Wood Project (Rogers et al, 2002), MPLS (Huang et al, 2010), LETS GO (Vogel et al, 2010), and nQuire (Mulholland et al, 2012). With respect to the integration phase, the appropriation of mobile technology in everyday school practices still seems to be problematic despite the extensive resources invested (Cerratto-Pargman & Milrad, in press; Ramberg, 2013).

It is nevertheless not surprising that mobile technologies have not been appropriated to any notable extent. Most studies attempting to show empirically and convince various stakeholders of the great potential of mobile learning have to a large extent been conducted through evaluations in the form of attitude surveys and interviews, putting emphasis on either learners’ motivation or teachers’ acceptance of the new learning innovation (Wingkvist & Ericsson, 2009; Sharples, 2009). While drawing attention to some of the learning outcomes, these studies lack critical analysis and evaluation of the learning processes (Vavoula & Sharples, 2008), and, most importantly, how they are transformed by the introduction of mobile technology. After all, according to the state of the art review of Wu et al (2014), most mobile learning projects employ quantitative methods and around 86% of them report positive outcomes, mainly in terms of motivation and attitudes. Research studies examining mobile learning activities have also shown that a large proportion of the pilot studies and trials conducted have been strongly technology-driven with no explicit educational foundations (Kukulska-Hulme et al, 2011; Traxler & Kukulska-Hulme, 2005). Given these arguments, it may not be too far-fetched to suggest that
mobile learning may be part of the repetitive cycle of technology in education suggested by Cuban (1986) and Oppenheimer (2007).

Undeniably, mobile learning has problematic aspects. For instance, little is still known about how learning can unfold across outdoor and indoor contexts, and how students’ technology-mediated learning processes should be scaffolded in complex outdoor environments. In a concept mapping study of 20 internationally acknowledged domain experts, Börner et al (2010) identified the following problem clusters as reflecting the central challenges of mobile learning:


2. Limitations for learning – covers challenges related to organizational and educational problems of educational institutions.

3. Contextual learning – covers aspects that highlight the relation between learning and the context in which the learning takes place.


6. Orchestrating learning across contexts – covers problems related to current educational practices and the management of learning across contexts.

The research problems this thesis addresses can be mapped to clusters (3), (4) and (6). Those problems relate specifically to the issue of orchestrating collaborative formal mobile learning activities with a particular focus on understanding the conditions for scaffolding and the learning and multiple interactions that unfold across contexts. Ultimately, in order to realize meaningful outdoors education supported by mobile technology, we need to acknowledge that learning needs to be scaffolded, planned for, organized, and orchestrated (Vygotsky, 1978, Wood, 2001; Dillenbourg, 2009).
Scope of the research enquiry and the research problem

We know from a socio-cultural point of view that appropriate assistance, i.e. scaffolding, needs to be provided in order to create the conditions for students to develop higher levels of understanding within the zone of proximal development (ZPD) (Vygotsky, 1986, Wood et al., 1976). When it comes to education in the context of the classroom, a rich scientific understanding exists of how learning can be scaffolded. However, little is still understood of how we provide, and in particular coordinate, scaffolding in complex outdoor contexts outside of the classroom walls.

In the field of Technology-Enhanced Learning (TEL), coordination of scaffolding interventions has been conceptualized with the notion of orchestration. Orchestration is, in this thesis, defined as ‘the process of productively coordinating supportive interventions across multiple learning activities occurring at multiple social levels’ involving multiple contexts, and multiple tools and media (Fisher & Dillenbourg, 2006, Dillenbourg et al, 2009). In particular, Dillenbourg et al (2009) delineated three dimensions of this coordination:

- Management of the cognitive dimension of the process, coordinating the learning processes taking place at different social levels (individual work, group work).
- Management of the pedagogic dimension of the process, by adapting the designed activities to the real occurrences of the educational system.
- Management of the technological dimension, by coordinating the transaction among the technological components.

Dillenbourg et al (2009) also give an account of several kinds of coordination that should take place within the frame of the three dimensions such as that focused on in this thesis: namely the coordination of the different scaffolding used (teachers, peers, tools, etc.) in order to obtain synergies among them. Thus, in this thesis, the study of orchestration is delimited to a focus on productive and synergistic coordination of scaffolding resources in across contexts mobile learning activities.

Orchestration remains one of the most important challenges of the mobile learning field (Börner et al, 2010), which is not unexpected. After all, the new learning scenarios envisioned within the mobile learning field change the conditions for orchestrating learning, and in particular for coordinating scaffolding. First, tools are not, as often perceived, neutral; in fact,
they are far from neutral as they alter our reality, reshape learning situations through constraining and enabling mechanisms, and mediate the way we interact and make sense of the world (Kaptelinin & Nardi, 2006; Vygotsky, 1986; Wertsch, 1997). Thus, just by introducing mobile technologies into learning situations we are enacting a significant change of conditions for orchestration. Second, contexts are not neutral either. By changing the context of learning, from a rather controlled and familiar classroom environment into a considerably less controlled context in which learners are both exposed to an overflow of unfiltered stimuli and have more restricted opportunities for communication and interaction (Winters & Price, 2005), we are further changing the conditions for orchestration. Third, envisioned pedagogical methods further contribute to changing the conditions for orchestration. It is one thing to orchestrate a traditional teacher-led classroom activity and quite another to orchestrate, for instance, a student-centred inquiry-based learning activity. Indeed, the pedagogical method in use dictates, among many things, the roles of students and teachers, the learning processes, how interactions should occur, and, most importantly, students’ scaffolding needs (Nouri et al, 2014).

Thus, if we are eager to contribute to the design of field trip mobile learning activities, we need, as a first step, to explore and understand how transformations introduced by technologies change conditions for orchestrating scaffolding. As a second step, we need to investigate how orchestrated mobile-supported field trip activities should be designed in order to meet learners’ scaffolding needs by taking the socio-technical conditions of our educational systems into account. Consequently, that is the aim of the research presented in this thesis.

Research questions and research approach

The following research questions have been formulated with the aim of finding out how to orchestrate mobile-supported field trip activities.

1. What are the challenges for scaffolding student learning in mobile-supported field trip activities across contexts?
2. How do we design orchestrated mobile-supported field trip activities that take students’ scaffolding needs into account?
3. How do we study orchestration of mobile-supported field trip activities?

I have chosen to examine these research questions in naturalistic contexts using a methodology whose application has spread within the learning sciences, namely design experimentation or design-based research (Barab & Squire, 2004; Brown, 1992; Collins, 1992).
Thus, in approaching the research questions a design-based research methodology (The Design-Based Research Collective, 2005) was adopted. More specifically, I relied on co-design methodology (Penuel et al, 2007) to iteratively design and evaluate mobile learning activities together with teachers, students and researchers from different domains.

Accordingly, the research questions formulated in the five articles included in this thesis have all been approached empirically by means of design-based research methodology. The articles are based on three empirical case studies, MULLE, mVisible I and mVisible II. The case studies are referred to as cases 1, 2, and 3 throughout the thesis. They were conducted in Stockholm, Sweden, from 2009 to 2012 and involved fifth-grade primary school students (age 12). The analysis of the three case studies has resulted in a set of published articles. For this thesis, five articles have been selected for a further cross-article analysis that is presented in Chapter 7, paving the way for the findings of this thesis (see Figure 1 for an overview).

Figure 1. An overview of the research approach and of this thesis
Delimitations

I would suggest this research work has the following delimitations:

First, the findings obtained in this research are not necessarily generalizable as they primarily concern children aged 11-12 years.

Second, the school subjects of mathematics and natural science that are mentioned in the research questions formulated in this work, were considered as the specific context for the study of orchestration of mobile learning activities and in this sense have not been specific object of this research.

Third, orchestration is a wide concept that can cover coordination of several aspects of learning activities. In this thesis, however, the concept is delimited to coordination of scaffolding.
Selected articles for this thesis


My contribution to this article was 75% of the analysis and writing process. I was also one of the designers of the case study.


I contributed to the planning, analysis and writing of the article. I was also one of the designers of the case study.


My contribution to this paper was leading the research project, 50% of transcription and coding of the data, 80% of the analysis, and leading the writing process.


My contribution to this article was 100% transcription and coding of the data, 75% of the analysis, and leading the writing process. I was also one of the designers of the case study.


My contribution to this article was 75% of the analysis and leading the writing process.
A selection of other articles within the thesis work


Overview of research articles

This thesis is based on a collection of five selected articles that stems from research efforts conducted in three different case studies. Case Study 1 focused on students exploring geometrical concepts outdoors with the support of mobile technology. Case Study 2 focused on students exploring species and their biotopes in a natural environment through using mathematics, and graphs and pie charts in particular, supported by mobile technology. Case Study 3 was a second iteration and development of mVisible 1.

The collection of articles can be divided into three parts; Articles 1 and 2 stems from the MULLE project and are explorative with respect to the nature of the research. These two articles aimed at highlighting critical concerns regarding the conditions for orchestrating scaffolded mobile learning field trips (Research question 1), and at delineating ways to serve students’ scaffolding needs better (Research question 2). The insights gained from the MULLE project lay the ground for the design of the mVisible 1 and 2 projects. Articles 3 and 4, both based on the mVisible projects, are more evaluative in nature, examining how the introduction of mobile technology into field trip activities transforms learning processes and the scaffolding needs of learners (Research questions 1, 2 and 3). Finally, Article 5, a methodological article, reflects on and presents the design process behind the three conducted projects and proposes a design framework for mobile learning in outdoor activities (Research question 2).

Article 1 - Exploring the Challenges of Supporting Collaborative Mobile Learning

In this article, we explored the specific challenges of supporting collaborative scaffolding in mobile learning contexts, asking how we can design mobile learning activities to provide the support collaborative scaffolding requires. To this end, we designed and analysed a mobile learning activity from an activity theory perspective. The learning activity was aimed at a group of primary school students using mobile technology with the objective of collaboratively practising the mathematical area concept in outdoor settings.

The analysis identified a set of challenges and factors for orchestrating collaborative learning in outdoor mobile learning activities.
Article 2 - Eliciting the Potentials of Mobile Learning Through Scaffolding Learning Processes Across Contexts.

This article took a closer look at how students’ learning activities should be scaffolded across contexts. Accordingly, focus was directed towards all available means, such as teachers, mobile technology, pre- and post-activities, and the activity sequence as a supportive structure. Consequently, a sequence of learning activities was identified within the domain of mathematics education. In particular, I questioned the scaffolding role which available resources can play in supporting students’ learning activities and, further, how we should orchestrate these resources across contexts in a pedagogically supportive manner.

The article showed a set of challenges that need to be considered when students’ mobile learning activities are scaffolded, and it demonstrated how a selection of these challenges can be addressed by teachers, mobile technology, sequencing of activities across contexts, and the utilization of pre- and post-activities in indoor contexts.

Article 3 - Mobile Inquiry-Based Learning. A Study of Collaborative Scaffolding and Performance

This article is grounded in the mVisible I study. The study was based on a sequence of inquiry-based mobile learning activities within the domain of natural sciences and mathematics education and was designed in the light of findings from Articles 1 and 2. Our general approach in this article was to investigate the scaffolding needs which arise in an orchestrated outdoor mobile learning activity, and which scaffolding needs are met through collaboration with peers, and which are not. In particular, we examined the effects of collaborative scaffolding, and the effects which technological scaffolding has on learning and performance. After quantitative analysis, we suggest that the use of mobile technologies has multiple effects, both positive and negative, on students’ learning and that the role of teachers remains just as crucial as it was before the introduction of mobile technologies.

Article 4 - Characterizing Learning Mediated by Mobile Technologies: A Cultural-Historical Activity Theoretical Analysis.

This article examines the potential of activity theory, and more specifically, second-generation cultural–historical activity theory (CHAT) for characterizing learning activities mediated by mobile technologies. To this end, an empirical study (Case Study 3) was designed with the goal of examining five small groups of students (fifth grade, age 12) who were using mo-
bile devices in authentic educational settings, within a natural science inquiry-based learning activity outdoors. Second-generation CHAT was operationalized as an analytical and dialectic methodological framework for understanding students’ learning activities mediated by mobile devices. Besides the specific operationalization of CHAT, and methodological reflections on the operationalization, the study contributes a characterization of mobile learning and identification of constraints and transformations introduced by mobile technology into students’ activities.

Article 5 - A Learning Activity Design Framework to Support Mobile Learning in Primary School

This article dealt with the following questions: how do researchers design innovative, pedagogical, orchestrated, usable and sustainable mobile learning activities for primary school children? This question is in the article answered by the introduction of the Learning Activity Design (LEAD) framework for the development and implementation of mobile learning activities in primary schools. The LEAD framework draws on methodological perspectives suggested by design-based research and interaction design in the specific field of technology-enhanced learning (TEL). The LEAD framework is grounded in four design projects conducted over a period of six years. It contributes a new understanding of the intricacies and multifaceted aspects of the design-process characterizing the development and implementation of mobile devices (i.e. smart phones and tablets) in curricular activities conducted in Swedish primary schools. This framework is intended to provide both designers and researchers with methodological tools that take account of the pedagogical foundations of technologically-based educational interventions, usability issues related to the interaction with the mobile application developed, multiple data streams generated during the design project, multiple stakeholders involved in the design process and sustainability aspects of the mobile learning activities implemented in the school classroom.

Contributions

The contributions of this thesis are: 1) further development of the Learning Design Sequence model as proposed by Selander (2008) into a model for orchestrating scaffolded mobile supported field trips; 2) a methodological framework for design-based research for mobile learning, and methodological reflections on the study of learning mediated by mobile technology; and 3) a critical perspective on the introduction of mobile technologies in educational settings.
Thesis structure

Chapter 1, Introduction, presents my research area, my specific scope of research enquiry, and an initial overview of the published articles that constitute the foundation of the research I present.

Chapter 2 introduces the Background of outdoor education and mobile learning.

Chapter 3 describes the Theoretical foundation that guided this research work.

Chapter 4, Methodological approach, presents the methodologies involved in my research.

Chapter 5, The case studies, describes the three empirical case studies and their aims and activities.

Chapter 6, Overview of the results, provides an overview of the results from the five articles included in this thesis.

Chapter 7, Cross-case and article analysis, presents an analysis which synthesizes and reconceptualizes the results from the selected articles.

Chapter 8, Discussion and future work, is a general discussion concerning the main conclusions and contributions of this thesis combined with my thoughts on future research.
Chapter 2: Background

Outdoor education as a concept and practice

The concept of outdoor learning is not new. In his classic novel *Emile*, the French philosopher Jean-Jacques Rousseau wrote as early as 1762 about the value of experimental approaches to learning and teaching, distinctly emphasizing education in nature and outdoor contexts (Rousseau, 1979). Several progressive educators have promoted the concept since then. One of them is John Dewey, who in *The School and Society* advocated for experiential learning in the local environment: ‘Experience [outside the school] has its geographical aspect, its artistic and its literary, its scientific and its historical sides. All studies arise from aspects of the one earth and the one life lived upon it’ (1980: p. 91).

Dewey introduced a perspective on learning as interplay between experience and interaction that significantly influenced the scientific literature on outdoor education, and, in particular, definitions of outdoors education. Take, for instance, the adopted definition of this thesis: ‘outdoors education is an experiential process of learning by doing, which takes place primarily through exposure to the out-of-doors. In outdoor education the emphasis for the subject of learning is placed on relationships, relationships concerning people and natural resources’ (Priest, 1986: p. 1). Priest (1986) bases this definition upon the following six major points. First, outdoor education is perceived as a method for learning. Second, the process of learning is experimental, with a focus on meaningful experiences in the educational process. Third, learning takes place primarily, but not exclusively, in outdoor contexts. Fourth, experimental learning makes use of the senses (sight, sound, touch, smell, taste) and involves cognitive, affective, and motoric aspects of learning. Fifth, the learning in outdoors education is based upon interdisciplinary curriculum matter; it is an approach that aims at achieving the goals and objectives of the curriculum. Finally, Priest (1986) emphasizes that learning outdoors comprises many relationships with such elements as natural resources, people, and society.

Hammerman (1973), another proponent of outdoor education, accurately emphasized a critical relation and difference between outdoors and classroom education, claiming that the purpose of outdoor education is to en-
rich, vitalize, and complement content areas of the school curriculum by means of first-hand observation and direct experience outside the classroom. Hammerman (1973) further stated that classroom instruction often deals with abstract ideas and non-real world experiences, whereas outdoor education may allow students who are often limited in terms of opportunities to interact with the natural world, a chance to do so in meaningful ways.

Indeed, historically, teachers have found several meaningful ways to conduct outdoors education, encompassing field trip explorations in subjects such as natural science, history learning in museums, situated language learning, and camping trips.

Studies on outdoor education

A large portion of research on outdoor education has been conducted on students participating in learning activities at particular sites such as natural and urban environments, and has demonstrated a wide range of cognitive, social, and curriculum-related benefits. These studies have, for instance, shown that outdoor education can enhance learning through holistic encounters with nature where knowledge and experience interact with all senses (Jordet, 2007; O’Brien & Murray, 2007). Additional studies have demonstrated that outdoor education can have a positive impact on students’ collaborative skills and interpersonal relationships (Amos & Reiss, 2012), as well as improve teacher-student relations (Lai, 1999). Not surprisingly, students also seem to remember outdoor education experiences for many years (Dillon, 2010).

Furthermore, research conducted by Rickinson et al (2004) suggests that fieldwork can lead to reinforcement between the cognitive and the affective domain, with each influencing the other and providing a bridge to higher order learning. The same authors conducted a literature review of research on outdoor education which critically examined 150 research articles published between 1993 and 2003, summarizing their findings as follows:

‘Substantial evidence exists to indicate that fieldwork, properly conceived, adequately planned, well taught and effectively followed up, offers learners opportunities to develop their knowledge and skills in ways that add value to their everyday experiences in the classroom … Effective fieldwork, and residential experience in particular, can lead to individual growth and improvements in social skills.’ (Rickinson et al, 2004: p. 5)
Furthermore, Jordet’s (2007) research on outdoor learning has demonstrated that the interaction between theoretical knowledge and realistic hands-on experiences is fundamental for successful teaching, determining the distinction between success and failure for many students. In fact, some studies, such as SEER (Rickinson et al, 2004) demonstrated that students using an environmentally focused curriculum scored 72% higher on academic assessments (reading, science, maths, and grade point averages) than students from traditional schools.

However, several of these authors have also noted that positive outcomes are strongly dependent on carefully and purposefully organized learning activities that include solid preparation work and follow-up activities indoors (Magntorn, 2007; Rickinson et al, 2004).

Mobile outdoor education

The concept and field of mobile learning

The mobile learning field is a relatively new field that explores the possibilities to support outdoor education with mobile technology. However, when mobile learning emerged as an educational research field in the mid 1990s, early approaches attempting to define mobile learning were strongly anchored on the use of mobile technology rather than on the pedagogical outdoor practice that mobile technology was intended to support. For a time, techno-centric conceptualizations of mobile learning, and the equating of the term mobile with mobile technology, were accompanied by a number of technology-driven projects with weak pedagogical underpinnings (Kukulska-Hulme et al, 2011). The aim of these projects was mainly to exploit a new generation of pen tablet and Personal Digital Assistant devices for learning (Kukulska-Hulme et al, 2011).

Techno-centric perspectives on mobile learning still prevail (Winters, 2007; Guy, 2009), although they do not remain unchallenged. In the last few years elaborated views of mobile learning have been articulated on understanding technology in the context of pedagogical practices (Naismith et al, 2005). This is a significant step toward the evolution of mobile learning, characterized by a shift of focus from an imprecise and inadequate foregrounding of technology towards a conceptualization of mobile learning that emphasizes social outdoor activities mediated by mobile technology.
As the field of mobile learning is gradually growing, new and elaborated conceptualizations of mobile learning are continuously produced, such as those focusing on the notion of mobility and those emphasizing the notion of mobile learning. This thesis is grounded in two such interrelated notions.

The shift of focus away from mobile technology, towards pedagogical practice, is encompassed by a broadening meaning of the term ‘mobile’. From such a perspective, mobility exceeds an exclusive link to technology or geographical independence. For instance, Sharples et al (2005) argued that by placing mobility as an object of analysis:

‘we may understand better how knowledge and skills can be transferred across contexts such as home and school, how learning can be managed across life transitions, and how new technologies can be designed to support a society in which people on the move increasingly try to cram learning into the gaps of daily life’ (p. 2).

Kukulska-Hulme et al (2011) added to this perspective by maintaining that context is the common denominator of different aspects of mobility: physical, technological, conceptual, social and temporal contexts of learning. The appeal of this definition is that it covers a spectrum of aspects that are relevant for and characterize mobile learning (see Table 1). With the affordances of mobile technology, for instance portability and the capability to collect and store data, approaches such as inquiry-based learning in and across different physical contexts have been promoted (Vogel et al., 2010; Spikol et al., 2009). Research has shown that mobile technology also affords unceasing access to information, thus supporting mobility in a conceptual space, in the sense that learning material can be accessible for a vast spectrum of learning topics independently of physical location. In addition, the communicational affordances of mobile technology may not only support a social context of learning in a specific physical context, but also give access to social contexts independently of physical contexts (e.g. web 2.0). Finally, the affordances mentioned may also increase the mobility of the learner in the temporal space as learning material is constantly accessible.

In adopting such an understanding on mobility, research into mobile learning can be regarded as ‘the study of how the mobility of learners, augmented by personal and public technology, can contribute to the process of gaining knowledge, skills and experience’ (Kukulska-Hulme et al, 2011: p. 159). Pachler et al (2010) share a similar understanding of mobile learning as they contend that it entail: ‘being able to operate successfully in, and across, new and ever changing contexts and learning spaces’ (p. 6). Such an understanding plays down
the technological component and emphasizes instead transformation of everyday life worlds into spaces for learning.

<table>
<thead>
<tr>
<th><strong>Mobility in physical space</strong></th>
<th>People on the move on the geographical plane across physical contexts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mobility of technology</strong></td>
<td>Portable tools and resources are available and carried around</td>
</tr>
<tr>
<td><strong>Mobility in conceptual space</strong></td>
<td>Learning topics and themes compete for a person’s shifting attention.</td>
</tr>
<tr>
<td><strong>Mobility in social space</strong></td>
<td>Learners perform within various social groups</td>
</tr>
<tr>
<td><strong>Mobility in temporal space</strong></td>
<td>Learning is a cumulative process involving connections and reinforcement among a variety of learning experiences across formal and informal learning</td>
</tr>
</tbody>
</table>

*Table 1. A notion of mobility and context, adapted from Kukulska-Hulme et al. (2011)*

As a result of new conceptualizations of mobile learning, numerous interesting projects have been conducted across various contexts with diverse target groups exploring the role of mobile technology as support for subjects and outdoor activities guided by a wide range of pedagogical traditions such as situated learning, inquiry-based learning, problem-based learning, collaborative learning, behaviouristic learning and informal learning (Naismith et al, 2005a; Pachler et al, 2010). However, in these research projects, transformations introduced by mobile technology in relation to outdoor activities have so far been overlooked.

**Studies on mobile outdoor education**

The number of case studies within the mobile learning field documenting pilots and trials is large and is still rapidly increasing, encompassing a spectrum of different target groups, subjects, pedagogical models, and contexts of learning. The literature review presented by Wu et al (2014), which examines 164 studies conducted between 2003 and 2010, demon-
strates that 52% of the inspected studies targeted higher education students whereas only 18% targeted elementary school students. The authors also suggest that language and computer sciences are the most popular subjects. Natural science and mathematics, two school subjects treated in the studies of this thesis, accounted for only about 3% of the whole.

Traxler (2009) distinguished the following themes in the mobile learning studies conducted:

1. Mobile learning centred on technology: a technological innovation is introduced in an educational context to measure its technological feasibility and educational possibilities.
2. Miniaturized and portable eLearning: it involves implementing solutions already used in eLearning environments after their adaptation to mobile terminals.
3. Classroom connected learning: applies mobile technologies in the classroom to support collaborative learning.
4. Individualized, situated, and personalized mobile learning: development and application of programs that help produce context-aware educational experiences.
5. Mobile training: the use of mobile technology to improve the worker’s performance through the delivery of information and just-in-time support for their immediate needs.
6. Mobile learning in remote and rural environments: application of mLearning in distance learning experiences in places where conventional eLearning has no reach.

The research work presented in this thesis is related to the third and fourth theme addressing formal learning across contexts with a particular focus on creating educational opportunities in meaningful outdoor contexts. These specific themes, concentrating on in- and across-context learning, have been explored in several other studies. Some of the projects, paving the way for the case studies of this thesis, are presented in the following.

Related mobile learning projects paving the way for the case studies conducted in this research work

The Ambient Wood project (Rogers et al, 2002) was one of the first mobile learning projects. The aim of this project was to explore how playful learning experiences can be created where children investigate and reflect on biological processes in a physical environment augmented with digital
abstractions. The planned learning activities in the project were designed to prompt children to learn when interacting with aspects of the physical environment supported by a variety of devices and multi-modal displays. The physical space that formed the basis of the experience was a real wood, inhabited by a rich collection of living and dead forms that the children identified, explored, and probed.

The *Bird and Butterfly Watching and Identification* project (Chen, et al, 2004) was another early innovative study of how mobile technologies can be used to support students’ learning about how to identify and characterize birds and butterflies. In this project, learners used mobile devices to photograph birds and butterflies that they observed in a natural environment and to access a knowledge database containing pictures and information about them.

The *MPLS or the Plant Identification* project (Huang et al, 2010) is a more recent project. MPLS was designed to improve the development and learning of a plant curriculum. In the MPLS project primary school students used mobile technologies to explore plants in a natural environment. The mobile technologies supported identification of plants by offering a manual search in a database with pictures of the plants or by image recognition that was applied to pictures taken by the students. After identification, information about the plant was made accessible.

The *MobileMath* project (Wijers et al, 2008) explored opportunities to support more playful ways to learn, in form of situated, embodied, and multi-modal game-based learning supported by mobile technology. The MobileMath design was grounded on research delineating the characteristics of engaging games and on principles derived from the theory of Realistic Mathematics Education (RME). MobileMath was a geometric GPS-based game offering lower secondary education students an opportunity to deepen their experimental knowledge of geometrical concepts such as angles, parallels, and perpendiculars related to quadrilateral shapes. The geometrical concepts were investigated through a game-based learning scenario that involved both authentic outdoor contexts and realistic problems.

*Go Math* (Alexander et al, 2010) is another interesting project that took advantage of opportunities for outdoor education supported by mobile technology. The Go Math project supported collaborative activity and encouraged mathematical talk and activity. The aim of the project was to exploit the fact that many sport-mad students use maths for keeping score in games they are watching and playing themselves. Thus, the learning activity offered opportunities for students to use ratios, percentages, and graphical representations to enrich their enjoyment of baseball games and
to help them track their own improvement. The mobile devices were used to calculate students’ statistics after each game, such as their on-base percentage, and to create graphs to track progress over time for comparison with major league players.

GEΩ (Spikol & Eliasson, 2010) was a project that aimed at exploring how mobile technologies can be used to support learning of geometrical concepts such as area and volume in outdoor environments. The learning activities were presented as an architectural mission where the students’ main goal was collaboratively to calculate and plan the design of a new building on the university campus. Mobile devices were used to provide task instructions and clues and to calculate distances through GPS functionality. Once a plan for the building was calculated and designed the students returned to the classroom to construct a 3D model.

A classification of the related mobile learning projects
All these projects view physical contexts as a material environment that incorporates authentic learning objects which the learners interact with and derive experience from. Consequently, in these projects, technology, in various ways, acts to support and enhance learners’ interactions with physical contexts. See Table 2 for a classification of the mobile learning projects presented in relation to this thesis.
<table>
<thead>
<tr>
<th>Project</th>
<th>Task</th>
<th>Role of Context</th>
<th>Role of Technology</th>
<th>Scaffolding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient wood</td>
<td>Identify habitat distributions and relations</td>
<td>Physical context is explored and analysed</td>
<td>Exploring light and moisture, providing text about the environment</td>
<td>A teacher provided task instructions and answered questions on the outdoor activity</td>
</tr>
<tr>
<td>Bird &amp; Butterfly</td>
<td>Identify birds and butterflies</td>
<td>Physical context is explored and analysed</td>
<td>Take photo, database with information of species</td>
<td>Teacher support through the software system in the outdoor activity</td>
</tr>
<tr>
<td>MPLS</td>
<td>Identify species of plants</td>
<td>Physical context is explored and analysed</td>
<td>Take photo, identify species</td>
<td>A teacher delivered instructions and facilitated discussions in the outdoor activity</td>
</tr>
<tr>
<td>Mobile Maths</td>
<td>Create shapes, rectangles, squares, and parallelograms</td>
<td>Physical context is explored and analysed</td>
<td>Capture areas on a map</td>
<td>Introduction and debriefing activity. Other support in the outdoor activity not described.</td>
</tr>
<tr>
<td>Go Math</td>
<td>Calculate ratios and percentages in sports games</td>
<td>Physical context is explored and analysed</td>
<td>Create graphical mathematical representations, store scores, track improvement</td>
<td>Task instructions provided by mobile technology</td>
</tr>
<tr>
<td>GEM</td>
<td>Calculate areas and volumes of buildings</td>
<td>Physical context is explored and analysed</td>
<td>Measure distance, task structure, give feedback and clues</td>
<td>Introduction and debriefing activity. Task instructions and clues from mobile devices.</td>
</tr>
</tbody>
</table>

*Table 2. A classification of related mobile learning projects*

However, in terms of scaffolding and orchestration from a scaffolding perspective, these projects illustrate the gap addressed in this thesis. None of the described projects have explicitly designed learning activities with scaffolding in mind or reported on the scaffolding perspective. Also, a detailed analysis of the projects reveals that implicit scaffolding elements exist in the learning activities, but those elements are few, isolated, and seemingly not explicitly coordinated and orchestrated. Overall, the projects reported do not provide insights into how mobile learning activities can be orchestrated.
Chapter 3: Theoretical foundation

This thesis is about mobile technology for learning. In relation to the pedagogical uses of technology every theoretical grounding requires, on the one hand, an understanding of what technologies are and what role they play in human activity, and, on the other hand, what learning is and how it is manifested in human activity. To meet these requirements, I have tended towards the socio-cultural perspective on learning: a perspective that views the use of technology and tools as a central tenet in learning. Approaches such as distributed cognition (Hutchins, 1995) or situated learning (Lave & Wenger, 1991) could be perceived as alternatives, as they share many epistemological and ontological assumptions with the socio-cultural perspective and acknowledge the role of technology. However, the socio-cultural perspective, compared with distributed cognition and situated learning, offers a powerful analytical framework that facilitates the analysis of technology-mediated learning activities through activity theory (Kapitelinin & Nardi, 2006; Engeström, 1987). Nardi (1996: p. 70) suggest that activity theory, in comparison with the aforementioned perspectives, is the most appropriate framework that ‘discards irrelevant details while isolating and emphasizing those properties of artefacts and situations that are most significant for design’. Another significant reason for choosing the socio-cultural perspective is that well-developed theories on how learners should be supported are offered, explicitly represented by the empirically well-researched concept of scaffolding.

This chapter introduces the socio-cultural perspective on learning and its core concepts: tool mediation, zone of proximal development, and scaffolding. The chapter ends with a presentation of the concept of orchestration, which in this thesis has been used to conceptualize the coordination of scaffolding.
The socio-cultural perspective on learning

Philosophers and researchers have debated where the boundary between cognition and the environment should be drawn since the very beginning, as manifested by the Cartesian mind-body dualism debate that has been around for centuries. The socio-cultural perspective, introduced by Russian psychologist Lev Vygotsky (1978) and further developed by scholars such as Bruner (1990) and Wertsch (1997), is convincingly overcoming mind-body dualism through its emphasis on the close coupling between cognition and environment. In the centre of this coupling, we find tools.

Unlike most psychological traditions of the time, the socio-cultural perspective, rather than considering culture as an external factor, saw it as the generative force responsible for the production of the mind (Kapetelinin & Nardi, 2006). This view is based on Vygotsky’s assumption that humans are born with a set of elementary mental functions, such as attention and memory, but develop higher mental functions, such as planning and decision-making, through social interactions with culture. For Vygotsky, social interaction precedes cognitive development; consciousness and cognition are the end-product of socialization and social behaviour. Furthermore, socio-cultural interactions, or human actions as Wertsch (1997) would phrase it, according to the socio-cultural perspective are never direct but mediated by socio-culturally constructed and meaningful tools; tools that can be both psychological, i.e. language and symbol systems, or physical, i.e. a calculator or a ruler.

In this perspective, human individual learning and development have their origins in social sources; the higher mental functions are developed when individuals internalize socially shared activities and appropriate meditational means made available in these socio-culturally meaningful activities (Lantolf & Lantolf, 2000).

It is here the power of Vygotsky’s thoughts is revealed, and its through this that sociocultural theory distinguishes itself from traditional cognitive approaches; namely in emphasis on the dynamic interdependence of social and individual processes and in particular the understanding of development as the transformation of social and tool-mediated activities into internal processes.

Tool mediation

The concept of tool mediation, Wertsch (1998) argues, is Vygotsky’s most important contribution and is essential for understanding the mind in so-
cio-cultural theory. Jerome Bruner (1962) emphasized Vygotsky's view on tool mediation:

‘He believed that in mastering nature we master ourselves. For it is the internalization of overt action that makes thought, and particularly the internalization of external dialogue that brings the powerful tool of language to bear on the stream of thought. Man, if you will, is shaped by the tools and instruments that he comes to use, and neither the mind nor the hand alone can amount to much.... And if neither hand nor intellect alone prevails, the tools and aids that do are the developing streams of internalized language and conceptual thought that sometimes run parallel and sometimes merge, each affecting the other.’ (Vygotsky, 1986: p. vii).

For Vygotsky, tools, primarily psychological but not excluding physical tools, mediate social and individual functioning and connect the social and the individual as well as the external and the internal (Wertsch & Stone, 1999). More importantly, tools qualitatively transform the mind and are essential in the mediation of higher forms of mental activity (i.e. higher mental functions). Vygotsky illustrated this through his classical example of the knot in an handkerchief; he argued that the knot serves as a reminder that extends the operation of memory ‘beyond the biological dimensions of the human nervous system’ (Vygotsky, 1978: p. 39) thus changing the psychological structure of the memory process. In this example, a process of memorizing is constructed that extends the bounds of our heads, and in which, the knot and signs transforms remembering into an external activity. Wertsch (1997) employs another example of semiotic mediation in a multiplication problem such as 343 x 822. Although it is possible to solve this problem mentally, the traditional approach would be to use a division algorithm such as long division:

```
   343
x 822
   686
  686
 2592
266328
```

Now, to paraphrase Wertsch (1997), a solution is reached through mediated actions that involve a meditational mean; a syntax in this case that has a certain external spatial organization and certain affordances (Gibson, 1977) that enable problem-solving. By using this particular meditational tool we reduce a mental problem to a series of external and concrete operations. Wertsch (1997: p.33) argues that, ‘in an important sense, then, the
syntax is doing some of the thinking involved’—thinking and external work that extend our mental capacities.

However, while tools and technology are often viewed as empowering and enabling actions, such views have a narrow focus as they only provide a partial understanding of how we relate to technology (Wertsch, 1997). Haas (1996) emphasizes the dangers of viewing technology exclusively from the perspective of what it can do, pointing to two myths arising from such views: technology is all-powerful and technology is transparent. The latter myth, Haas (1996) explains, postulates that technology is a kind of distortionless window; that learning activities supported by mobile technology are not changed in a substantive way by the transparent medium of mobile technology. Along with Haas, other socio-cultural scholars focusing on tool mediation (Kaptelinin & Nardi, 2006; Rabardel & Bourmaud, 2003; Vygotsky, 1986; Wertsch, 1997) have claimed that tools reshape learning situations and transform activities. More importantly, in relation to the myth that technology is all-powerful, an important aspect of meditational means is occasionally overlooked; namely that meditational means also constrain actions, and that, in fact, ‘any attempt to understand or act on reality is inherently limited by the meditational means we necessarily employ’ (Wertsch, 1997: p. 40).

Scaffolding

Because Vygotsky placed tool mediation at the centre of the development of human cognition, social origins take on a special importance in his theories (Cole & Wertsch, 1996). We are, after all, not born with the tools that mediate our higher mental thinking; they are cultural tools which belong to the cultures of which we are part. It is through interaction with culture, and more particularly in interaction with members of cultures, that our paths of cognitive development start. As asserted by Vygotsky’s well-known law of genetic development: ‘Every function in the child’s cultural development appears twice: first, between people (interpsychological) and then inside the child (intrapсhycological … All the higher functions originate as actual relationships between individuals’ (Vygotsky, 1978: p. 57). Thus, for Vygotsky, social and cultural factors have primacy over individual cognitive processes: ‘The social dimension of consciousness [i.e., all mental processes] is primary in time and fact. The individual dimension of consciousness is derivative and secondary’ (1979: p. 30).

This set of considerations led Vygotsky to the concept of internalization, which is the process whereby the individual, through interaction with oth-
ers, actively reconstructs external operations on the interpsychological plane and shifts them onto the intrapsychological plane (Vygotsky, 1978). Consequently, internalization reflects individuals’ process of mastering elements such as language and sign systems. Taking language as an example, Bakhtin (1981) further emphasizes the role of internalization:

‘The word in language is half someone else’s. It becomes “one’s own” only when the speaker populates it with his own intention, his own accent, when he appropriates the word, adapting it to his own semantic and expressive intention. Prior to this moment of appropriation, the word does not exist in a neutral and impersonal language (it is not, after all, out of a dictionary that the speaker gets his words!), but rather it exists in other people’s mouths, in other people’s contexts, serving other people’s intentions: it is from there that one must take the word, and make it one’s own.’ (pp. 293-294)

However, to fully understand Vygotsky and his notion of cultural development as it relates to learning, one has to proceed to his concept, the Zone of Proximal Development (ZPD). Vygotsky defined ZPD as follows: ‘higher level of potential development level as determined through problem solving under adult guidance and in collaboration with more capable peers’ (Vygotsky, 1986: p. 86). This concept thus emphasizes the role of others, and in particular the need for guidance in the internalization process in order to reach higher development levels. Vygotsky stipulated that the - by a more capable - guided and mediated activities would be internalized by the child and “become part of the child’s independent developmental achievement” (Vygotsky, 1978, pp. 90). As noted by Levykh (2008), Vygotsky’s ZPD reflects learning as a cultural process of assistance through cooperation and collaboration. Hence, enabling a learner to bridge the gap between the actual and potential development level depends on the kinds of support provided; support can come from a teacher or an adult or in the form of collaborative learning with peers. Such support within the ZPD has been conceptualized by the metaphor of scaffolding. In the following sections, I will expand on the scaffolding metaphor and its manifestations.

Teacher scaffolding
Scaffolding has traditionally been defined as the process by which a teacher or a more knowledgeable peer provides assistance that enables learners to solve problems and carry out tasks which are beyond their unassisted efforts (Wood et al, 1976). The notion of scaffolding is strongly linked to the work of Lev Vygotsky, and in particular to the concept of ZPD.
In defining the nature of the guidance that promotes development, Wood et al (1976) suggested six types of support that an adult can provide: recruiting the child’s interest, reducing the degree of freedom by simplifying tasks, maintaining direction towards task-relevant goals, highlighting critical features of the task that the child might overlook, controlling frustration, and demonstrating ideal solution paths.

From the perspective of Wood et al (1976), three elements are central to scaffolding: first, a shared understanding of the goal of the activity, which is attained when the adult and the child collaboratively invest in and take ownership of the task; second, the adult provides appropriate support based on an ongoing diagnosis of the child’s current level of performance and understanding. Wood et al (1976) stated:

‘The effective tutor must have at least two theoretical models to which he must attend. One is a theory of the task or problem and how it may be completed. The other is a theory of performance characteristics of the tutee. Without both of these, he can neither generate feedback nor devise situations in which his feedback will be more appropriate for this tutee, in this task at this point in task mastering. The actual pattern of effective instruction then will be both task and tutee dependent, the requirements of the tutorial being generated by the interaction of the tutor’s two theories.’ (p. 97)

The final key feature of scaffolding is fading the support provided to the learner as the learner gains in proficiency (p.97). This feature is related to Vygotsky’s notion of internalization. From a Vygotskian perspective, psychological development progresses from a social (interpsychological) to an individual (intrapsychological) plane through the process of internalization. In this terminology, fading thus entails motivating and supporting the learner to internalize learning processes and allowing the learner to take control and responsibility for their learning.

A rather new conceptualization and categorization of scaffolding support are offered by Hill and Hannifin (2001). They identified four types of scaffolds: conceptual, metacognitive, procedural and strategic. Conceptual scaffolding is understood as assistance that simplifies complex concepts or highlights the relationships among various concepts. Metacognitive scaffolds on the other hand help learners to assess what they know and how they are learning, and to consider alternative ways to address a problem. Procedural scaffolds clarify requirements and show learners how to use resources or procedures in order to reach a goal. Strategic scaffolds provide alternative approaches to engaging in a task. Yelland and Masters (2007) included two additional scaffolding types: affective, which consist
of encouragement and praise (reduction of frustration), and technical, which include technical instructions and technical help (for example, retrieving a technical mistake).

Reviewing the literature on scaffolding, one can also observe a general emphasis on task construction and task sequencing. In terms of research on mathematics education, the importance of sequencing and decomposing tasks in a supportive manner is particularly stressed (Anghileri, 2006). In line with this, pre- and post-activities are highlighted as effective supportive scaffolds if designed appropriately. The pre- or introduction activities can offer an opportunity for learners and teachers to create a shared understanding of the main activity and its curriculum goals, set expectations, provide motivation, and also provide the necessary skills that students may not be familiar with (Puntambekar & Hübsher, 2005). Post- or follow-up activities on the other hand, can offer an opportunity for re-representing, emphasizing, and clarifying key points and concepts, and an opportunity for the teacher to assess the students and provide feedback (Yelland & Masters, 2007).

Since its inception, the scaffolding metaphor has been described and represented in a number of ways. These have included guided participation (Rogoff, 1990), reciprocal teaching (Palincsar & Brown, 1984) and the cognitive apprenticeship model of Collins et al (1989). As a result of considerable research on the nature of guidance that promotes learning, the scaffolding metaphor has been extended and applied more broadly to include various types of support. Scaffolding is consequently no longer restricted to interactions between individuals as artefacts, resources, curricula and environments are also used as scaffolds (Puntambekar & Hübsher, 2005).

Peer scaffolding
Contemporary theories on collaborative learning, which are mainly derived from Piaget’s cognitive development theory and Vygotsky’s socio-cultural theory, view collaboration as a mutual engagement between peers that predominantly perform the tasks together (i.e. low division of labour). The underlying presumption is that social and engaging interactions such as conflict, explanation, negotiation, mutual regulation, and co-construction of knowledge are means for effective learning to happen (Dillenbourg, 1999; Johnson & Johnson, 1985; Slavin, 1996).

Vygotsky contributed to the view on learning as a social phenomenon, and development as starting in the interpersonal plane, where cultural artefacts, both technological and symbolic tools, are shared through social
interactions and then internalized by the individual on the intrapersonal plane. In this line of reasoning, engagement in collaborative activities is assumed to enable individuals to master concepts and tools which they cannot do on their own. Thus Vygotsky’s concept of ZPD is key to the understanding of mechanisms of collaborative learning (Lehtinen, 2003). Put differently, the proposed claim with empirical support is that collaboration with a more capable peer can result in higher levels of cognitive development and understanding than can be achieved by the individual alone (Slavin, 1996).

Social interaction plays a fundamental role in the process of cognitive development. In contrast to Piaget’s understanding of child development (in which development necessarily precedes learning), Vygotsky suggested social learning precedes development. Piaget’s (1926) contribution on the other hand is based on the conception that social and arbitrary knowledge - language, values, rules, morality and symbol systems – can only be learned in interactions with others (Slavin, 1996). The interaction between peers is also important in logical-mathematical thought in terms of disequilibrating the child’s egocentric conceptualizations and in the provision of feedback to the child about the validity of logical constructions (Lehtinen, 2003). Essentially, for Piaget, action and interaction play a crucial role in the development of rationality and logical thinking.

Technology scaffolding

Some time ago, Rosenshine and Meister (1992) suggested that a scaffold may be either a tool, where a resource such as a cue card is provided for the learner, or a technique, that is, a strategy that the teacher implements in order to support a learner. This line of thought extends the scaffolding metaphor to include material tools, and recently educational technology (Sherin et al., 2004; Lajoie, 2005), has produced a productive line of research work.

In fact, during the last two decades plenty of research has been conducted around the educational implementation of scaffolding through technology. The results have been promising and indicate that technology, including computers and handheld technology, may be able to scaffold learners – for example with prompts that trigger reflection, hints that highlight critical features, and through the provision of simple feedback (McLoughlin, 1999; Reiser, 2004; Wood, 2001; Roschelle et al, 2010). Technologies have also been used to scaffold and structure complex tasks; for instance, in inquiry-based learning activities, by breaking down complex activities into more manageable ones (Wang & Kinzie, 2009).
These positive examples of scaffolding through technology are only a few of many, and there is certainly more hidden potential of technology for scaffolding learning to investigate. However, research conducted so far has clearly demarcated the current limitations of technology. Ultimately, technology fails to deliver that which is in the very core of scaffolding; namely individual, adaptive and calibrated support, including fading, based on the learner’s current understanding (Pea, 2004; Puntambekar & Hübsher, 2005). The indications are, however, that the teacher will for some time to come still have an important - if not a central – role in providing the scaffolding required for effective learning to happen, and technology will have a complementary and supporting role.

Scaffolding through representations and multiple semiotic modalities

Another popular topic within the educational research literature on mathematics and science education is the use of multiple representations as scaffolds (Wood, 2001; Arcavi, 2003; Quintana et al, 2004; Puntambekar & Hübsher, 2005). In such contexts, the representational affordances of technology are frequently described. For instance, Arcavi (2003) states, and portrays with excellent examples, how technology through visualization capabilities can help the learner to see that which otherwise cannot be seen in terms of both physical objects and abstract concepts. In line with this reasoning, Quintana et al (2004) maintain that tools can support learners by using representations that connect with the learners’ intuitions and also map onto expert practice. They assert that the tool scaffolds the learner to make connections between their own ways of thinking and formalisms used in expert practice. This line of thought is similar to Suthers’s (1998), who also stresses the scaffolding role of representations by claiming that concrete representations of abstractions turn conceptual tasks into perceptual tasks. Consequently, to cite Suthers, ‘symbolic representations such as diagrams can help learners “see” and internalize abstractions’ (p. 3).

Current research on mathematics and science education builds upon conceptions such as Suthers’s (1998), exploring the scaffolding role of multiple semiotic modalities in constructing meaning (Jewitt & Kress, 2005; Kress et al, 2001; Lemke, 2002; Tang et al, 2011).

The semiotic multimodal research approach, theoretically elaborated by Selander and Kress (2010) and Kress (2010), among others, takes its departure from the premise that meaning-making and communication can be scaffolded and performed through multiple semiotic resources defined as modes. Modes, Kress (2010) explains, are socially shaped and culturally
given semiotic resources for making representations and meaning. Kress (2010) further argues that the modes configure the world differently, that they offer distinct ways of engaging with the world and distinctive potentials for representing the world, and that they can therefore be seen as ‘cultural technologies’ of transcription. Some examples of modes are gestures, sounds, texts, pictures, and speech.

Interestingly, mobile technology’s representational and multimodal data collection and transformation capacities have the potential to scaffold a multimodal way of learning and meaning-making. The challenge in terms of teaching is however, as Jaipal (2010) stresses, that researchers and educators need to understand the potential of different modes and the dynamic nature of the interplay of modalities. As Jaipal (2010) observes, such understanding ‘can help science educators make decisions on how to select and sequence modalities in ways that support students’ learning’ (p. 49).

Orchestration

This chapter has so far illustrated that learning can be supported by various scaffolding resources such as teachers, peer collaboration, technology, and representations of different kinds. However, in order to reap the benefits of these scaffolding resources and optimize supportive learning experiences in formal mobile learning activities, reflective planning, regulation, and coordination are required. One such reflective approach, revitalized in recent years in the field of technology-enhanced learning (TEL) and computer-supported collaborative learning (CSCL), is based on the metaphor of orchestration and on the idea of teachers as ‘orchestrators’ (DiGiano & Patton, 2002; Fischer et al, 2005; Gravier et al, 2006; Dillenbourg & Fischer, 2007; von Inghold, 2009; Dillenbourg & Jermann, 2010).

Accordingly, the term orchestration has been used, within the frame of socio-cultural learning (Kollar et al, 2011; Mercer et al, 2010; Hämäläinen & Häkkinen, 2011), to describe the process of ‘managing a whole learning group in such a way as to maintain the progress towards the learning outcomes and improvement of practice for all’ (Moon, 2001: p. 120). Others define orchestration more specifically in terms of productively coordinating complex socio-technical learning systems involving multiple activities across multiple contexts mediated by multiple tools and media (Fisher & Dillenbourg, 2006; Dillenbourg et al, 2009). Dillenbourg et al (2009) delineated three dimensions of this coordination.

- Management of the cognitive dimension of the process, by coordinating the learning processes taking place at different social levels (individual work, group work).
• Management of the pedagogic dimension of the process, by adapting the designed activities to the real occurrences of the educational system.

• Management of the technological dimension, by coordinating the transaction among the technological components.

These authors also give an account of several kinds of coordination that should take place within the frame of the three dimensions, such as that described in this thesis; namely the coordination of the different scaffolding used (teachers, peers, tools, activity structures, etc.) in order to obtain synergies among them. This view on orchestration was enriched by Prieto et al (2011), who, after a literature review focusing on orchestration, proposed a more comprehensive definition. This is represented graphically in Figure 2.

![Figure 2. A graphical representation and conceptual overview of orchestration, adapted from (Prieto et al., 2011).](image)

The graphical representation in Figure 2 is probably the most comprehensive overview of what the concept of orchestration entails, answering several important questions starting from what orchestration is, to where orchestration takes place, to how orchestration is done, and so on. As can be noted, orchestration is viewed as supportive interventions and coordination; for instance, it involves processes such as group management, time management, classroom management, assessment, and workflow of activi-
ties. The orchestration is planned and performed by the teacher. This, of course, stresses the importance of the teacher’s role as leading the students towards the learning outcomes (Dillenbourg & Jerman, 2010).

However, the role of the teacher is not limited to orchestration in real time during the progress of an activity, but typically embraces orchestration of the whole lifecycle of a learning activity, from its design and planning to its enactment and subsequent evaluations (Prieto et al, 2011). In terms of what is orchestrated, resources such as multiple activities, social levels, and media/tools are emphasized. Furthermore, these resources are orchestrated in multiple contexts involving for example face-to-face situations, blended learning environments or distance learning.

Traditionally, within the field of TEL, orchestration is done through micro and macro scripts incorporated in the design of activities, tasks, and tools, or/and through social interventions performed, for example, a teacher. Scripts emerge within the field of TEL as a method that shapes the way collaboration occurs in teams triggering specific types of interactions that are known to generate learning gains (Dillenbourg & Jermann, 2010). An example of a micro-script is prompts that increase conflicts within a team, whereas a macro-script can be a combination of an individual activity and a class-wide activity that encourages the constructions of individual opinions which later are problematized in collaboration with peers.

However, the conceptual model of Prieto et al (2011) does not emphasize constraints. Dillenbourg et al (2011) stress the need to pay attention to these, however, when orchestration is designed. Dillenbourg et al (2011) give an account of four essential constraints that should be considered: 1) the curriculum (what), 2) the contents (what's inside), 3) how people learn (how), 4) the learners (who). Other important constraints are also mentioned, such as assessment constraints, time constraints, energy constraints, and space constraints (Dillenbourg et al, 2011).

Although orchestration has attracted a lot of attention within the field of TEL, the theoretical and empirical exploration of the concept is rather new within the field. Thus, existing research on orchestration is still far from providing rich and complete answers to the questions Prieto et al (2011) ask in the overview presented in Figure 2, resulting in several knowledge gaps in the scientific literature. Among the gaps, Prieto et al (2011) especially emphasize the need for more research and knowledge related to the question of how orchestration is performed. So far, according to these authors, research work and practice in orchestration seem to polarize two methods of orchestration, the automated, technologically-mediated form provided by computationally represented scripts, and the manual, socially-mediated method where teachers use spoken language
and gestures to manage activities. Several of the answers to other questions, such as which aspects to orchestrate, what is orchestrated, or the constraints to take into account, etc., are also in need of further enrichment and development.

Furthermore, research on orchestration has so far primarily focused on learning within the context of classrooms (Prieto et al., 2011; Dillenbourg et al., 2011, 2012). That of course applies, for example, to the constraints described by Dillenbourg et al. (2011) and the conceptual overview presented by Prieto et al. (2011). Consequently, knowledge about orchestration produced from these research efforts to some extent reflects the specific conditions and qualities of classroom learning, and may not be directly transferable to and applicable in learning situations with different conditions and qualities. Further theoretical and empirical investigations of other learning situations are therefore needed. It is against such a background that this thesis set out to explore constraints, challenges and aspects to be considered in the orchestration of mobile learning activities across contexts, and to construct a usable and tailored model that answers the question of how to design orchestrated mobile learning activities with a particular focus on the coordination of scaffolding.

The learning design sequence model for orchestration of learning

Existing models and frameworks with a socio-cultural grounding which may inform the construction of a tailored model for orchestrating scaffolded mobile learning activities are rare. Nevertheless, the learning design sequence model introduced by Selander (2008) is one such model, originating from a socio-cultural view on learning, and proposed as a conceptual tool for the orchestration of learning activities (Kjällander, 2011; Bundsgaard & Hansen, 2011).

More specifically, the learning design sequence model (LDS) rests on a design perspective that views learning as socio-semiotic meaning-making processes in which learners form and transform signs through different modes (Selander & Kress, 2010; Selander, 2008). Here the concept of design refers to the transformation process whereby students and teachers act as didactic designers in interaction with each other and different resources (Kjällander, 2011).

The LDS model can be seen as the organization of a number of fundamental elements in formal learning sequences, starting from the teacher’s introduction of a subject and a learning activity to summative assessment of the same activity (Kjällander, 2011; Selander, 2008). Bundsgaard and Hansen (2011) argue that the LDS depicts a workflow that accentuates
different aspects of the complex processes in formal learning situations and is put into practice through teacher orchestration.

Figure 2. The formal learning design sequence model (Selander, 2008)

In particular, the LDS model organizes the learning process as a sequence of three units, a setting unit followed by two transformation units, namely the primary and the secondary transformation units (see Figure 3). Selander (2007) argues that the setting unit is a central element of the learning sequence which makes the learning tasks and their goals clear. In the primary transformation unit, the students collaboratively make meaning by forming and transforming knowledge from the available information by using different resources and artefacts. During this phase the teacher also makes formative assessments of the learning processes and intervenes when necessary to scaffold the students. In the secondary transformation unit the focus is on how the students create representations based on their gained understanding, and how they present these representations. This cycle includes the students’ discussions of and meta-reflections on their learning processes and results, and the opportunity for the teacher to perform summative assessments.

In this context, the notion of orchestration is twofold. On the one hand, it represents pre-orchestration as entailing how the teacher - framed by institutional norms, curricula, and available resources - plans tasks, assembles learning material, selects modes and artefacts, and plans the workflow and its coordination. On the other hand, it represents run-time orchestration as entailing the teacher’s formative and summative feedback along with their scaffolding interventions.
Thus, the LDS as an orchestration model has several merits. First, the model answers what is to be orchestrated, namely, the students’ formation and transformation of signs and representations, the modes and artefacts used in that process, and the teacher’s scaffolding interventions. Second, the model answers how the orchestration of formal learning activities should be done, namely, through sequencing a workflow in the form of a setting and two transformation units in which the teacher’s scaffolding role is outlined in general terms (i.e. summative and formative assessment/feedback). The particular usefulness of the LDS model for understanding and analysing the teacher’s scaffolding role in learning activities has also been empirically evaluated by Stålbrandt and Hössjer (2006).

However, the LDS model is mainly grounded on and empirically evaluated in traditional classroom contexts. Therefore, the utility of the LDS model for orchestrating mobile learning needs to be further investigated and the particularities of mobile learning situations taken into account. Apart from this thesis, no documented uses of the LDS model exist in the field of mobile learning.
Chapter 4: Methodological approach

Over the past few decades, educational research has been criticized for its failure to contribute to classroom practice and educational change. As Hammersley (2002) asserts, the role of research has come to be seen by many educational researchers more in terms of an ‘enlightenment’ movement than an ‘engineering’ movement. Rather than producing, validating, and supplying effective pedagogical techniques, policies, or innovative learning activities, the pay-off of research is now, as Hammersley (2002) notes, widely believed to lie more in terms of raising questions about current assumptions or supplying alternative perspectives on teaching and educational policy. The gap between research and practice within the domain of education is indeed well documented, and also in terms of research conducted in the mobile learning field (Cerratto-Pargman & Milrad, in press).

The guiding purpose of this thesis is both to add to the existing theoretical knowledge in the mobile learning field and to contribute usable conceptual tools and artefacts for school practice. With this dual purpose, relevant methodological approaches are limited to action research and design-based research (DBR) which have been presented as methodological alternatives to approaches that produce little impact on educational practice (Collins et al., 2004; Brown, 1992). Although these two alternatives share a pragmatic orientation and many epistemological and ontological underpinnings (Cole et al., 2005), I have found design-based research especially applicable, for two main reasons. First, compared with action research where the educator is usually conducting the research and is viewed as both researcher and teacher (Kuhn & Quigley, 1997), design-based research focuses on a collaborative partnership between researchers and practitioners (Anderson & Shattuck, 2012). Put differently, the DBR approach recognizes the restrictions and capacities of teachers and researchers in conducting educational research, viewing both actors as indispensable and complementary. I believe this is a sound perspective, as teachers may be ill-trained to conduct rigorous research, and researchers may not posit sufficient knowledge of the everyday complexities and needs of the educational systems.

Second, DBR compared with action research has a pronounced focus on,
and has developed methodologies for, designing and understanding material artefacts (Järvinen, 2009).

In the following, a brief overview of design-based research is provided, followed by an overview of the design-based research approach adopted in this thesis.

Design-based research

Since the seminal work of Brown (1992) and Collins (1992), DBR has been broadly adopted within educational research and reflected in numerous discussions about conceptualizations and development of frameworks and methods for conducting educational design research (Wang & Hannafin, 2005). DBR approaches in educational research largely grew out of criticism by numerous researchers, practitioners, and policy-makers who claimed that the findings from educational research have little impact on practice or the evolution of theory (Collins et al., 2004; Brown, 1992). For instance, Brown (1992) asks to what extent we are driven by a pure quest for knowledge and to what extent we are committed to influencing educational practices.

Central to DBR are the construction, design, implementation and evaluation of educational interventions; such interventions are not simply intended to show the value of a particular curriculum in a local setting but also to advance a set of theoretical constructs (Cobb et al., 2003), and to identify reusable design principles and design patterns (Reeves, 2006). Essentially, DBR has developed as a way to carry out formative research to test and refine educational practices based on theoretical principles derived from previous research (Collins et al., 2004). According to Collins et al. (2004), what characterizes DBR is a process of progressive refinement, which involves putting a first version of a design into the world to see how it works, followed by iterative revisions based on experience. For example, van den Akker (1999: pp. 3-5) identified the following four sub-domains of DBR: curriculum, media and technology, learning and instruction, teacher education and didactics. Such approaches to design-based research separate instead of cultivate its interdisciplinary nature.

Against this background, DBR methods are suggested to compose a coherent methodology that bridges theoretical research and educational practice (The Design-Based Research Collective, 2003). This bridging is facilitated by the fact that the methods are grounded in the needs, constraints, and interactions of local practice, ensuring that research outputs have a bearing on educational practices. DBR envisions that researchers,
practitioners, and learners/users will work together to produce or facilitate a meaningful change in contexts of educational practices. That being so, participatory design methods are frequently utilized in the field of TEL (Mor & Winters, 2007).

According to Wang and Hannafin (2005) the term DBR can be understood as encompassing a paradigm described by different terms in the literature including: design experiments (Brown, 1992; Collins, 1992); design research (Cobb, 2001; Collins et al, 2004; Edelson, 2002); developmental research (van den Akker, 1999); developmental research (Richey & Klein, 2005), formative research (Reigeluth & Frick, 1999). Lately, terms such as design learning inquiry (Mor, 2013), interdisciplinary design in technology enhanced learning (IDR) (Winters & Mor, 2008) and design science of e-learning (Mor, 2010) have appeared in the literature about design methods in the field of technology-enhanced learning (TEL). In this respect, DBR entails a series of approaches with the intention of producing new theories and practices and artefacts that account for learning and teaching in educational practices. Central to DBR, however, is its focus on design; design considered as a membrane between research and practice (Spikol, 2010).

The design-based research methodology adopted

Design experiments are quite common in the field of mobile learning. However, a large proportion of the studies have often been enacted in a conspicuous way. On the one hand, many questionable DBR approaches have been techno-centric, guided by a strong interest in designing mobile technologies, instead of designing learning activities that make use of mobile technologies (Traxler & Kukulska-Hulme, 2005). On the other hand, multiple mobile learning studies conducted in schools have lacked clear pedagogical foundations and grounding in educational needs (Kukulska-Hulme et al, 2011).

Research efforts within the mobile learning field have in their endeavours overlooked methodological and practical questions related to the methods and frameworks necessary to put in practice, on the one hand, to design sustainable educational activities in cooperation with practitioners and learners and, on the other hand, conduct relevant research studies about the usability of the designs implemented as well as their feasibility and sustainability. Indeed, design for mobile learning has become a critical challenge (Walker, 2007). From our own design-based research experi-
ences we are aware of some of the challenges associated with designing innovative and sustainable learning activities such as informing design with learning theories, grounding it in sound pedagogical principles, building design on current pedagogical practices and educational needs, and facilitating the use of technology by means of robust and usable mobile devices.

Because of these challenges, in this thesis, a tailored design-based research design was adapted which was inspired by procedures and techniques stemming from interaction design. The primary strength of the interaction design tradition is that it provides a set of techniques for putting a design innovation in context, in alignment with users’ needs, current practices, and usability issues (Löwgren & Stolterman, 2004). Interaction design techniques such as future workshops, prototype development, and methods for evaluation, are specifically developed to address the challenge of designing the social components of a learning system together with the technical components as a usable and appropriate systematic whole (Löwgren & Stolterman, 2004). Thus, interaction design has properties that can facilitate the orchestration of the cognitive, the pedagogic, and the technical dimensions of socio-technical learning systems as described by Dillenbourg et al (2009).

The three empirical case studies described in this thesis have all been designed with teachers and students. We used a DBR process supplemented with methods from interaction design. The design process in the three design cycles showed some minor differences but had a common approach in terms of the following five phases (especially Case Studies 2 and 3): 1) describing current learning and teaching practices, 2) envisioning pedagogical practices, 3) prototyping envisioned pedagogical practices, 4) implementing mobile learning activities, and 5) evaluating mobile learning activities (see Figure 4).

Each one of the phases of the design process is described and exemplified in the mVisible I project which was conducted in cooperation with a primary school in the north of Stockholm, Sweden (see Chapter 5).
The five design phases followed for the design of the mobile learning activities

Phase 1: Describing current learning and teaching practices

This phase consisted of helping designers and researchers to understand how learning and teaching practices are organized in a specific educational institution and to identify both the challenges and the opportunities of current practices.

The tools used to collect and document data during this first phase were mainly: future workshops conducted with students (Kyng & Greenbaum, 1991) in Case 2 & 3, and interviews conducted with the teachers in all case studies. The future workshops consisted of a structured brainstorming session containing three stages: the critique, the fantasy, and the implementation. During the first phase of the process we worked with the critique stage, attempting to understand current learning activities from the students’ perspective. Thus, the main goal was to let the students generate representations of how learning activities from their perspective unfolded in the classroom. For example, in Case 2, we wanted to know how the students studied natural science and mathematics today, focusing on the different activities involved such as calculating, reading, writing, and presenting to the class. Focus was also on the problems and difficulties students experienced with learning the school subjects. Examples of questions discussed from Case 2 were: what is difficult in mathematics? what is
difficult in solving and presenting solutions to mathematical problems? what is difficult in natural science education?

This stage was important for giving the students the opportunity to construct representations that could be used as a point of departure during the critique and fantasy stages of the future workshop.

This phase was completed by conducting interviews with teachers and a literature review of past educational research. The interviews aimed at investigating teachers’ experience of what students perceived as difficult in subjects selected for the project. The literature review of past educational research investigated pedagogical challenges associated with natural science and mathematics education.

Phase 2: Envisioning pedagogical practices

This phase consisted of generating visions of innovative pedagogical practices based on two input sources: theoretical frameworks within pedagogy and practical input from students’ and teachers’ visions. The theoretical knowledge provided us with a scientific grounded model for learning, and students’ and teachers’ input grounded the innovation in the actual working and learning conditions of the end-users. For instance, in Case 2 & 3 the theoretical input came from the pedagogical framework of ‘inquiry-based learning’, whereas Case 1 derived inspiration from the framework of problem-based learning.

The practical input came from two sources, namely interviews with the teachers and the future workshop with the students. Prior to the fantasy stage the students were briefly introduced to inquiry-based learning and asked to envision potential learning activities supported by mobile technology within the frame of inquiry-based learning.

For example, in Case 2 the fantasy phase ended with a summary whereby students distributed in groups presented the visions they had written on post-it notes. The researchers clustered the collected students’ visions in an affinity diagram (see Figure 5). After consultation with the teachers, one vision was chosen for further development.
Phase 5: Prototyping for pedagogical practices envisioned

The goal of this phase was to produce and assess a tangible prototype of the envisioned pedagogical practice developed together with students and teachers in phase 2 of the design process. For example, in Case 2, two prototypes, namely a paper prototype and a digital hi-fi prototype, were developed and tested with the students.

The aim of generating the paper prototype first was to carefully examine the pedagogical sense of the core ideas present in the envisioned pedagogical practice chosen. Then a complete digital hi-fi prototype was developed to turn the focus onto technology and usability issues instead of prioritizing the pedagogical ones. In Case 2, the approach applied in the generation of the paper prototype test meant letting one group of three students go through the envisioned mobile learning activity by using a paper prototype. The paper prototype consisted of printouts of the screens shown on the mobile devices and on the common tool (see Figure 6). Two facilitators simulated the functionality of the mobile devices by handing over paper versions of the screens to the students as they progressed through the activity. The approach applied in producing the digital hi-fi prototype test, which was informed by the paper prototype test, meant letting another group of three students go through the envisioned mobile learning activity but differently from the paper prototype this activity was conducted with the actual mobile devices and the designed software system (see Figure 7).
After evaluation of both types of prototype it is important to create an inventory of identified obstacles and problems. For instance, in the mVisible 1 project, on the one hand, the paper prototype test informed us that the design activity encouraged students to work individually instead of collaboratively. The hi-fi prototype test (see Figure 7), on the other hand, informed us that the QR information was too complex for the students, that the task design encouraged the students to avoid reading the QR information, and that they had problems scanning the QR codes.

In order to further develop the pedagogical innovation and solve the inventory of problems and obstacles elicited in the prototype tests, new requirements were defined or improved. The set of specified requirements informed the implementation phase.

Phase 4: Implementing mobile learning activities

The goal of this phase was to implement the whole activity system, including software, learning tasks, learning scripts, scaffolding, etc., based on: input from previous research, own design experiences, design patterns, and evaluation results of the prototype testing. The design disciplines involved in the implementation phase were interaction design, learning design, and computer science.
From an interaction design perspective focus was put on enhancing the usability of the device; for instance, in terms of interaction with the interface and its features. Usability requirements were elicited through an interaction analysis of prototype testing. From a learning design perspective, focus was put on constructing 1) educational texts and task instructions, 2) collaboration scripts, 3) scaffolding structures and resources, and 4) designing the sequence of tasks and activities. From the computer science perspective focus was put on completing the software system and further aligning the technology with the learning activities, which concretely entailed taking care of bugs and faults encountered in the prototype tests, implementing reviewed tasks, taking account of collaboration scripts and scaffolding changes, along with the usability requirements.

In all case studies, after implementation of the whole learning activity systems, pilot tests were planned and conducted. The approach in the pilot tests meant letting a group of three students perform the whole activity with the complete technological system. This allowed us to evaluate the learning activity system holistically for further redesign and optimization.

Phase 5: Evaluating the mobile learning activity implemented

The last phase of the design cycles was to evaluate the local impact of the designed learning activities. The evaluations comprised an analysis of how well the interventions satisfied the end-users and what educational and interactional effects the interventions had on learning. These evaluations, reported in the publications included in this thesis, were based on the data collected by means of video, audio, interview, and survey data.

Data-collection

Design-based research interventions generate a vast amount of data (Brown, 1992). The studies reported in this thesis produced a diverse set of data (i.e. field notes, questionnaires, interview answers and audio- and video recordings). See Table 3 for an overview of the data collection procedures. However, the primary method of data collection throughout the three case studies was video and audio recordings of students and teachers’ verbal and non-verbal interactions. To record the students’ conversations, a small microphone was attached to each student in all case studies. Researchers recorded the video material with close-up and wide-angle cameras; close-up cameras for collecting group interaction data, and wide-angle cameras for capturing complementary angles out of range of the close-up camera.
Table 3. Data collection in the case studies

Essentially, the video-based interaction analysis facilitates a holistic study of students’ learning processes, which involve verbal and non-verbal interactions; both needed to be observed considering the nature of the research questions asked. After all, conversational analysis alone would not have captured knowledge-building activities that are performed in other modalities than speech; for instance, the students’ physical interactions with the mobile devices, or their gestural and embodied ways of interacting with the learning objects.

The video data from the close-up cameras were primarily used in the analysis and complemented with the wide-angle cameras only when necessary for clarification.

In Case Study 1, the students were also interviewed before and after the designed learning activities. This was the phenomenographic method (Marton, 1986), which aimed to investigate changes concerning their conceptual understanding of the concept of area. In Case Studies 2 and 3, individual pre- and post-test questionnaires were used in a complementary manner to investigate the effect the designed learning activities had on performance. In Case Study 3, the students were group interviewed after
the performed activities to investigate attitudes and motivational aspects. The teachers were interviewed formally or informally in all three case studies.

Data analysis

The research questions investigated in the case studies were certainly related, yet they were different to the extent that different analytical approaches were required. In the collection of articles comprising this thesis, guidance on analysis was received from three different sources; cultural-historical activity theory, the Formal Sequence Design model, and interaction analysis. In the following, these three are described along with descriptions of how they were adopted and utilized.

Cultural-historical activity theory

Second-generation cultural-historical activity theory (CHAT) was applied in the analysis in Articles 1 and 4. CHAT provides a set of concepts proven to be useful in the study of technology-mediated learning activities and transformations introduced by learning technologies (Kaptelinin & Nardi, 2006; Engeström, 1987; Nezamirad et al, 2005).

CHAT, as suggested by Cole (2005), has its roots in the Russian cultural-historical school founded by Vygotsky (1978) in 1920. According to Daniels (2001), we can distinguish three generations of CHAT that are incremental and overlapping. The first generation is associated with Vygotsky’s theory of cognition and development of higher mental functioning. Vygotsky’s work shows the role that tools and artefacts along with people play in the mediation of human actions and human development in a social setting (Vygotsky, 1978). The powerful mediation of human action is well illustrated in a simple triangle showing that the relationship of subject-object is always mediated by tools. For Vygotsky (1978) human beings seldom interact with the environment directly without using cultural artefacts (i.e. technical and/or semiotic tools) acting as mediators of human behaviour.

Vygotsky’s triangle was further developed by one of his colleagues, Alexei Leont’ev. Leont’ev (1974, 1978) suggests a theory of activity that specifies a hierarchical structure of human actions on three levels: activities at the top, actions in the middle, and operations at the bottom of the triangle. Leont’ev’s theory of activity contributes a refined understanding of the concept of the object of the activity. According to Leont’ev, all human activities are directed towards objects that motivate actions, i.e. activities
are understood as mediators of interactions between subjects and objects (Kaptelinin & Nardi, 2006) and activities can be analysed at three hierarchical levels - activity, actions, and operations. Actions are conscious and goal-directed, undertaken to fulfil the object of the activity, whereas operations are routinized, unconscious, and automatic components of actions.

The concept of the object of the activity introduces thus the motives, intentions, and pursuits of the human actions that become a valuable criterion for the distinction of different activities, especially collective (i.e. at the level of activity) and individual (i.e. at the level of actions and operations). Dynamic relationships between levels are common and enable transformations from one level to another level within the activity system. Leont’ev’s model of activity is known as activity theory (Kaptelinin & Nardi, 2006). Activity theory is a descriptive tool as well as a theoretical framework that aims to understand human beings through an analysis of the genesis, structure, and processes of their activities (Kaptelinin & Nardi, 2006). The framework uses the concept of activity, which is understood as the subject’s purposeful interaction with the world, as the fundamental unit of analysis, and offers a set of concepts that can be used to conceptualize a model of activity systems.

Drawing on the work of Vygotsky and Leont’ev, Engeström (1987) suggests a second-generation theory that proposes an expanded view of the activity system. Such expansion takes account of the social and institutional rules governing activity systems along with the notion of community and division of labour organizing the activity system. Engeström (1987) proposes an extended activity system model (see Figure 8), including the subject-tool-object relation of Vygotsky, but with a description of activity as a collective phenomenon, as opposed to Leont’ev, who almost exclusively focused on individual activities (Kaptelinin & Nardi, 2006). In order to account for the social structure of activities, Engeström (1987) included three additional components: 1) rules that regulate the subject’s actions; 2) the community of people who share a common object; and 3) the division of labour – how tasks are divided between the community members.

Engeström’s second-generation activity system model thus depicts constitutive components of tool-mediated and collaborative activities, such as the mobile learning activities that were the object of study in this thesis. For instance, the notion of division of labour stresses the collaborative aspect and provides means for making a distinction between cooperative and collaborative processes (Nezamirad et al, 2005). Rules on the other hand regulate the relationship between a person and the community of which he or she is a member, as well as the relationship between a per-
son/community and the technology. Rules also emerge with the introduction of technology. Thus, the notions of rules and community allow us to analyse how the learning activities we study are regulated, facilitated, and constrained. Furthermore, the notions of hierarchical structure and dynamic transformation between activities, actions, and operations facilitate an in-depth analysis of the transformations introduced by mediating artefacts such as, in our case, mobile devices.

![Activity System Model](image)

**Figure 8: The activity system model (Engeström, 1987)**

The third generation of CHAT, proposed by Engeström (2009), pays attention to the ways in which people have to work and move across boundaries within networks of activities (Timmis, forthcoming). In Articles 1 and 4, we chose to operationalize Engeström’s second generation theory from students’ conversations and interactions with the environment based on collected video data and transcribed conversations.

In Article 1, we paid attention to the interactions between the different components of Engeström’s model displayed by Figure 1 when analysing students’ technology-mediated collaborative processes. In Article 4, the concept of instrumental mediation introduced by Rabardel (1995) was added to the analytical toolbox, which facilitated the understanding of transformations, specifically instrumentations, observed in the analysis of the mobile learning activity studied. In Article 4, we also employed the dialectical method of analysing emerging contradictions in students’ activities, guided by the conviction that it is important to take into account the contributions of technologies in constraining actions in authentic settings (Timmis, forthcoming).
The formal learning design sequence model

In Article 2, the focus was on exploring how students’ learning processes in general should be scaffolded across contexts. In order to conceptualize and describe the mobile learning activities in question, the Learning Design Sequence model (LDS) provided by Selander (2008) was used in a slightly modified form (described in detail in Chapter 2).

In the analysis the three different learning activities of this study were conceptualized according to the learning design sequence model (see Figure 9). That being so, the introduction activities were mapped to the unit setting in the model, but reframed and highlighted as the first transformation unit. Accordingly, the outdoors activity was mapped to the primary transformation unit (second transformation unit), and the post-activity to the secondary transformation unit (the third transformation unit). Within this conceptualization we asked: 1) how the students could be scaffolded within each unit, by means of the teachers and the technology; and 2) on a general level, how the units as isolated entities, and the sequence of units as a whole, could support the students’ learning processes. The reasons why the LDS model was used are threefold: it views a sequence of activities as a coherent whole, it explicitly highlights different relations between units in a sequence, and it describes a sequence of activities that resemble the designed activities of this study.

The collected data were then divided into three parts: introductory data, outdoor activity data, and post-activity data. For each part, episodes were identified and transcribed in which the interactions between the students
and the teachers, or the students and the mobile technology, could be categorized according to the six types of scaffolding support presented by Hill and Hannafin (2001) and Masters and Yelland (2002), i.e. conceptual, metacognitive, procedural, strategic, affective, and technical. One example of such an interaction is a teacher helping out with a technical problem, i.e. providing technical scaffolding.

Regarding the use of the LDS model in general, I found it beneficial to conceptualize the orchestration of the scaffolding support and the activities in terms of a learning sequence. From a methodological perspective, the LDS model offered two advantages by making different relations between units in a sequence explicit. First, it can be used as a conceptual design tool in the design process to encourage us to explicitly consider each designed unit in a learning sequence as a meaningful and dependent pedagogical part of the whole. That should facilitate the orchestration of mobile learning activities. Second, for the same reasons, the LDS model can be used as a tool a posteriori in the design-based research process to evaluate whether a learning activity design is pedagogically sound and meaningful.

**Ethical considerations**

Before the three case studies, a letter of consent to participation was provided to the parents of the students (see Appendix 1), fully describing the aims and the nature of the research projects and the data collection procedures. We further assured them that collected data would be stored in such a way that it would be impossible for outsiders to access them and that the data would only be used for research purposes. The students were also given the opportunity to withdraw from participation at any time without suffering negative consequences.
Chapter 5: The case-studies

Case Study 1: Mulle

The MULLE research project (Maths edUcation and pLayful LEarning) was conducted in Stockholm, Sweden, in the autumn of 2009 and aimed at fifth-grade primary school students (age 12).

The overarching goals of the research team were to get the students away from the desk and to make mathematics more tangible by providing opportunities for the students to collaboratively, playfully, and in an embodied manner, solve mathematical problems in authentic contexts with concrete content and physical manipulatives. In doing this, we mainly drew on socio-cultural and situated perspectives of learning (Vygotsky, 1986; Lave & Wenger, 1991).

Participants

The study was held in Stockholm, Sweden, in the autumn of 2009. More specifically, it took place in the surroundings of Rösjöskolan, a local primary school. The participants in the study came from that particular school. In total, there were six fifth-grade students aged twelve, divided into two groups. Two teachers were involved throughout the study.

Learning tasks and activities

In total, four sub-activities were designed and performed: two indoor introductory activities, an outdoor field activity, and an indoor post activity. The students worked in two groups of three. Two teachers participated in the learning activities.

The aim of the activities was for the students to practise the area concept on a both procedural and conceptual level. On a procedural level, the focus of the practice was on familiarizing the students with different area calculation and construction methods, in terms of both formulas and approximation techniques. On a conceptual level, the aim was to provide tasks that encouraged the students to reflect upon how areas are constituted and how they can be decomposed, that different shapes can have the
same area, and that the relation between the lengths of the sides of a shape determines the area of that shape.

**The introduction activities**

The first introductory activity in the study was *familiarization with the devices*. The activity aimed at giving the students hands-on experience with the mobile devices used in the outdoor activity. Each student was given four tasks to complete on each of the two types of mobile phones we used, the primary device with a nine-key keypad (Nokia N95) and the secondary device with a touch screen (Nokia XpressMusic 5800). We observed the students (1) successfully used the keypad to navigate the phone and that they (2) managed to navigate two instances of tabbed interfaces present in the standard phone software interface.

The second introductory activity in the study was *familiarization with the outdoor field activity*. It took place five days before the outdoor activity. The aim was to let students come prepared to the outdoor activity with experience of how the devices operated in the field and with a representation of the tasks and the learning goals. First, a short film from the pilot trial was presented to show the students what the field studies looked like. Then we introduced the scenario.

**The outdoor field activity**

The scenario for the outdoor activity consisted of an imaginary, almost extinct, species which had to be relocated from the local wild animal park. The students' task was to see that the new enclosures for the animals had the right measurements.

The two groups of three received the mobile devices to be used outside the school. After a short introduction they were told to follow the instructions on the primary device. The primary device told them to go to a meadow on the other side of the woods. When they entered the small field (see Figure 11), the primary device signalled that they were in the right location.

In the small field, the groups were introduced to the first task and asked to guess the area of two small rectangles marked by plastic cones. The rectangles had different lengths and widths but were both 12 m$^2$ in area. Each group had prepared one 1x1 m cardboard square to measure the areas. After completing a task they sent the answer in order to receive a new task. When they guessed and calculated the areas correctly they received a message on the primary device to go to the big field for the second task.
In the big field, the students were asked first to guess and then to measure the area of a large rectangle. The large rectangle was approximately 4000 m$^2$ and had cones to mark the corners. The students measured each side of the rectangle with the mobile devices and the implemented GPS measurement functionality. The third and last task was to go to another field nearby and to create their own rectangle of 4000 m$^2$. The outdoor activity ended with the children showing their constructed area to one of the teachers.

The indoor post-activity
The scenario for the indoor post-activity was the design of an amusement park. The area of the park was known in advance, and the children had to calculate an appropriate length and width, and to draw the plan with pen and paper. Similarly, they had to place attractions and service facilities, each with a certain area, in the amusement park they had created. The objective of the post-activity was to let the children repeat and re-represent the tasks performed outdoors, but this time in more abstract terms, aided by the concrete experiences gained outdoors. The post-
activity also aimed at creating an opportunity for the teacher to clarify concepts, assess the students, and provide feedback.

Case Study 2: mVisible I

The research project mVisible I was conducted at Stockholm University, and aimed at investigating students’ scaffolding needs in field trips guided by inquiry-based learning. The learning activities were played out in the woods to explore characteristics of different plant and tree species as well as their biotopes in the north Stockholm area, Sweden.

Participants

Seven groups of three students, 21 in total, took part in the study. The students were from the same fifth-grade class, participating in the study as part of their mathematics and natural sciences curriculum. Having due regard to which students could work together and which could not, the teachers used high heterogeneity as the basis for group formations. Six out of seven groups had both female and male students and the differences in background knowledge on the subject were as large as possible in all seven groups.

Learning tasks and activities

The inquiry-based learning activity with mobile support

The mobile inquiry-based learning activity was divided into three main activities, namely an indoor introduction, an outdoors field activity, and an indoors post-activity.

The introduction activity provided the students with an opportunity to both familiarize themselves with the technology intended to be used in the outdoors activity and to develop an understanding of the tasks they had to perform – guided by the attendant researchers and teachers who facilitated the process and provided instructions. The technology used consisted of a smartphone and a pad.

The field activity started with a group of students arriving at one of four different nature squares in the forest behind the school. Each student had a smartphone, and there was one common device, a pad, located at each nature square. The squares were designed for the purpose of the study and contained the relevant flora to be investigated by the students. Furthermore, the field activity was designed as a sequence of four tasks (see Fig-
As follows; in the **first task** the three students in the group used their mobile devices to **scan the QR code for the nature square** they had arrived at. The code initialized the mobile devices to show a list of what species were available in the current nature square. The common device also provided students with further task instructions. The **second task** to be performed was to individually use the mobile devices to scan QR codes attached to each species in order to identify them. The **third task** was to read information about the scanned species; this was followed by the **fourth task**, which was to use the phone camera, to capture what the students believed characterized the species. For the fifth and last task, the three students reconvened at the common device, where they used a pie chart to **calculate the distribution of trees in the area**. Also on the common device, they had to define what type of forest they were on basis of the distribution of trees. Tasks 2 to 4 were performed for each of the listed species in the nature square.

**Figure 12. Students trying to find a species**

The mobile device provided the students in situ with descriptions of species and their biotopes and allowed for multimodal data collection in the form of pictures and videos. The pad, on the other hand, constituted a common tool that scripted the collaboration between the students by forcing the students to provide individual codes each time a task instruction was needed from the pad. Its use was intended to encourage the students to create a joint task understanding and receive equal task information to avoid empowering them asymmetrically (Nouri et al, 2011). The teachers’ role in this particular activity was to intervene and support the students only when they were actively asked to do so through a phone call.
Figure 13. The five tasks in the outdoors mobile learning activity

The *indoors post-activity* was planned to let the students analyse the collected multimodal data from the outdoors activity. The students, collaboratively, had to interpret, transform the data collected, and summarize them as conclusions and new representations, i.e. the students transformed representations by making use of different modes and consequently making visible their understanding of species and biotopes (Selander, 2008; Selander & Kress, 2010). The activity ended with the students displaying multimodal presentations that were discussed together with the whole class. Two teachers scaffolded the students’ work during this post-activity.

**Case Study 3: mVisible II**

The research project mVisible II was a follow-up study to the mVisible I study and aimed at investigating *differences between* traditional field trips and inquiry-based field trips with mobile devices in terms of children’s learning processes and outcomes. The study consisted of two groups of students performing two different learning activities, namely, an inquiry-based learning activity supported by mobile technology and, as an addition to mVisible I, a traditional learning activity without technological support. Both of the learning activities were played out in the woods to explore characteristics of different plant and tree species, as well as their biotopes in the north Stockholm area, Sweden. In mVisible II, the mathematical fifth task of mVisible I was removed (students were supposed to construct pie charts).

**Participants**

A total of 30 students from two different classes took part in the study. They were divided into two groups independently of the class they belonged to: a ‘mobile group’ consisting of 15 students who performed a mobile learning activity, and a ‘traditional group’ consisting of 15 students.
who performed a traditional learning activity without mobile technology. The students in the mobile learning group were further divided into five groups of three. The teachers orchestrated this group division and high heterogeneity with respect to subject knowledge was achieved.

Learning tasks and activities

The inquiry-based learning activity with mobile support
The mobile inquiry-based learning activity was divided into three main activities, namely an indoor introduction, an outdoors field activity, and an indoors post-activity just as in mVisible I. The learning tasks of mVisible II were similar to the learning tasks of mVisible I, with the exception that the fifth mathematical pie chart task was excluded (see Figure 13 for a list of tasks).

![Figure 14. Students trying to find a species](image)

The traditional learning activity without technological support
A control group performing a traditional field activity without technological support was added to mVisible II. Similarly to the mobile learning activity, the traditional learning activity was divided into three activities: an introduction activity, a field activity, and a post-activity. The aim of the introduction activity was to let the students develop an understanding of the objectives of the traditional learning activity and what was to be done in the field and post-activity.

The field activity for this group of 15 students differed from the mobile learning field activity. In this particular field activity the teacher guided the students to the same nature squares as in the mobile learning activity. While in the nature squares with the students, the teacher provided information about the different species and their biotopes, asked the students questions and gave them an opportunity to ask their own questions. The
field activity ended with the teacher taking pictures of the species and collecting branches, leaves, and needles.

In the *post-activity*, first all of the collected materials were put on a table, then the teacher started a discussion about the characteristics of the different experienced species in the nature squares, and finally the teacher invited the students to examine the collected material.
Chapter 6: Overview of the results

In the following chapter, the main findings obtained in the research articles are presented. This chapter is followed by an analysis across the case studies and the selected research articles, resulting in a reconceptualization of the research results.


In this article, we explored the specific challenges of supporting collaborative scaffolding in mobile learning contexts (Case Study 1), asking how we can design learning activities which provide the support peer scaffolding requires. The main finding of the article indicates that the incorporation of mobile technology into mobile learning activities, if not designed properly, can strongly constrain the possibilities for collaboration and learning. More specifically, the analysis made it evident that the distribution of devices and functionalities within them predetermined the roles of the students within each group, their division of labour, and thus the learning processes to which they had access.

Thus, the findings of the study indicate that it is essential, on the one hand, to carefully examine what type of learning and collaborative opportunities mobile technology will be able to open up so that collaborative mobile learning activities can be planned accordingly. On the other hand, it is crucial to negotiate with designers and developers the technical configuration of devices and functionality that predetermine the dynamics of learners’ collaboration. Essentially, it is important that we ask ourselves how we empower learners with the configuration and distribution of mobile technology and what that entails in terms of accessibility to essential learning processes. In the case study analysed, the students became asymmetri- cally empowered and had unequal conditions for learning because of an asymmetrical distribution of the functionalities embedded in the mobile devices.

In this article, I explored challenges related to scaffolding student learning across contexts (Case Study 1), looking beyond the specific focus we put on peer scaffolding in Article 1. In particular, I asked what sort of scaffolding role available resources, such as teachers, mobile technology, pre- and post-activities, and activity sequences, can play in supporting students' learning activities and, further, how we should orchestrate these resources across contexts.

The analysis performed showed that it might be beneficial to conceptualize orchestration of scaffolding across contexts in terms of a learning design sequence (Selander, 2008) consisting of an indoor introduction activity, an outdoor field activity, and an indoor post-activity. On a specific level, the findings obtained indicate that pre-activities constitute an opportunity for the students to appropriate the technology used outdoors and create a shared task understanding. To put it in the terminology of Laurillard (2007), the introductory activities constituted an opportunity to familiarize the students with the prerequisite discursive/conceptual and practical/procedural tools. With regard to post-activities, it was demonstrated that they could compensate for scaffolding needs potentially unmet in prior activities. The post-activities offered opportunities for the teacher to assess the students, fade scaffolding support when evaluated necessarily, and provide types of scaffolding support restricted in the outdoor context. The post-activity also constituted an opportunity to put the focus of the learning on a higher abstraction level, allowing the students to utilize concrete experiences gained in the outdoor context, and to familiarize themselves with the associated formal and abstract scientific concepts. Another central finding of the article was that teachers, if readily available, could play a very influential scaffolding role.
Article 3: Mobile Inquiry-Based Learning. A Study of Collaborative Scaffolding and Performance

Our general approach in this article was to investigate the scaffolding needs that arise in an orchestrated outdoor mobile learning activity (Case Study 2), which scaffolding needs are met through collaboration with peers, and which scaffolding needs are not. More specifically, we examined the effects of collaborative scaffolding, and the effects which technological scaffolding has on learning and performance.

On a general note, the findings obtained demonstrated that, as researcher, designers, and teachers, we should not rely on peer collaboration to unfold to provide adequate scaffolding. The analysis performed demonstrated a negative correlation between students' scaffolding needs and their performance scores. Thus, the findings indicate that collaborative scaffolding amongst young students can have a negative impact on learning, especially if the students are not capable and knowledgeable enough to provide the required scaffolding. These findings re-emphasize two things: first, the important role of teachers in these kinds of activities; and, second, the importance of a reflective technology and activity design. Our analysis suggests that the mobile technology used, with all its utilized positive affordances, also gave rise to problems among students managing the technology and to scaffolding interactions that had significant negative influence on performance scores.

The analysis presented in this study also suggested that designers, whether researchers or teachers, should thoughtfully consider how learning activities across contexts are planned for, taking account of the scaffolding needs that different tasks, learning processes, and learning contexts can give rise to. One should, for instance, not put too much focus on conceptual learning in outdoor contexts, where teachers are not as readily available and the students concerned are believed to be incapable of providing the required conceptual scaffolding to their fellow group members. Essentially, designers of mobile learning activities across contexts should thoughtfully ask which learning tasks are suitable for different contexts and how learning tasks can be distributed across contexts in order to provide students with the required scaffolding for meaningful learning to occur for as many as possible.
Article 4: Characterizing Learning Mediated by Mobile Technologies: A Cultural-Historical Activity Theoretical Analysis.

This article examined the potential of activity theory and more specifically of second-generation cultural–historical activity theory (CHAT) for characterizing learning activities mediated by mobile technologies. To this end, an empirical study (Case Study 3) was designed with the goal of examining five small groups of students (fifth grade) who were using mobile devices in authentic educational settings, within a natural science inquiry-based learning activity outdoors.

The CHAT analysis conducted in this article demonstrated that the introduction of mobile technologies in the context of formal education is not unproblematic. By tracing students’ instrumentalizations of the mobile technologies provided, we identified several contradictions and tensions in the activity systems. On a general note the findings obtained pointed to the unfolding of learning activities that can be characterized as mechanical rather than reflective. One reason for students’ tendencies in this direction was that the activity systems allowed, and in some cases encouraged, students to instrumentalize the mobile technologies in non-intended ways towards non-intended objects, resulting in contradictions and tensions.

Nevertheless, we find the main reason for students’ tendency towards unreflective actions towards non-intended objects is the lack of available teachers regulating students' selections of objects and instrumentalizations of the tools used. A teacher monitoring the activities could have scaffolded the students by directing them towards relevant learning objects and relevant tool instrumentalizations. A teacher could also have scaffolded students to resolve emerging contradictions and tensions in constructive ways. Consequently, the main conclusion that can be drawn from the study conducted is that orchestration of formal mobile learning activities is a challenging task, as students may redesign and instrumentalize technologies used in non-intended ways – negatively affecting the unfolding of activities. That main conclusion also shows that orchestration of outdoor mobile learning activities is strongly dependent on that teachers monitor and orchestrate students’ activities in situ.
The article dealt with the following question: how do researchers design innovative, pedagogical, orchestrated, usable and sustainable mobile learning activities for primary school children? In answer to that question, the Learning Activity Design (LEAD) framework was developed and introduced for the sustainable development and implementation of orchestrated mobile learning in primary schools. The framework, which is based on the three case studies of this thesis, is intended to provide designers and researchers with tools that can help them to identify, evaluate, and develop mobile learning activities in school. The LEAD framework (see Figure 15) takes account of the following aspects of mobile learning devices used in education: pedagogical foundations, usability, managing multiple data streams, multiple stakeholders, and the sustainability of the implementation.

Figure 15. The five design phases of the LEAD framework
Chapter 7: Cross case and article analysis

This chapter presents an analysis across the case studies and the selected research articles presented in this thesis. The results obtained from this analysis consist of two parts. The first part describes aspects and challenges that need to be addressed when scaffolded mobile-supported learning activities are orchestrated. The second part explains how these aspects can be addressed through an orchestration model.

Orchestrating mobile learning activities: activity aspects and challenges

Fischer and Dillenbourg (2006) devised a concept of orchestration that explains different forms of coordination, of which the coordination of scaffolds is one. However, what is lacking is, on the one hand, the identification of scaffolding resources that need to be orchestrated and, on the other hand, the identification of specific challenges related to orchestrating these scaffolding resources, especially taking the particularities of mobile learning contexts into account. The first part of this chapter addresses this gap.

In analysing the outcomes obtained across the case studies, I have identified an emerging set of scaffolding aspects that I suggest are central for orchestration of mobile-supported field trip activities (see Table 4).
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*Table 4. An overview of the scaffolding aspects identified*
Social level: Balancing individual and collaborative activities

All three case studies were informed by socio-cultural methods of learning, thus entailing both individual and collaborative learning processes. In attempting to study how to scaffold these learning processes we identified a number of challenges in the case studies conducted.

The general concern has been how individual and collaborative learning processes should be scaffolded and balanced by taking into account the following: 1) which processes/activities are suitable for individual work and which ones are suitable for collaborative work; 2) the available resources to scaffold individual work versus collaborative work; and 3) the implications of differentiating individual and collaborative work. Further, different specific challenges were raised in the three case studies.

In Case Study 1, the focus of Article 1, I observed that the learning design caused an undesirable cleavage of individual and collaborative learning processes, empowering some students to the detriment of others with the consequence that students received access to different learning processes and learning trajectories. The main reason for this undesirable separation of individual and collaborative learning processes was that the students had access to different tools and functionalities that determined their roles in the learning activities.

In Case Study 2, I have attempted to address the challenge of asymmetrical student empowerment through promoting collaboration scripts and equal access to tools and functionalities. In this sense, the issue of asymmetrical empowerment was solved, but I observed two new challenges. In Article 3, I observed that students’ collaborative scaffolding did not meet their needs and, in fact, that collaborative scaffolding correlated with negative performance scores in post-tests. This observation primarily emphasized the need to support students’ learning processes with other scaffolding means than collaboration and it constituted a new challenge. The other observation, also presented and discussed in Article 3, was that otherwise low-achieving students belonging to groups with less pronounced and less effective collaborative work showed most learning gains in mobile learning contexts compared with the class as a whole.

In Case Study 3, the focus of Article 4, the collaboration processes were further analysed and it was concluded that students may construct and pursue shared non-intended objects in the absence of teachers regulating students’ learning activities.
This led me to the conclusion that the activity design implemented both solved and raised issues regarding collaborative processes. It also provided the students with a structure and support for productive individual work, thus emphasizing the challenge of orchestrating scaffolded learning activities that enable a productive balance between individual and collaborative learning processes.

Teacher’s role in outdoor mobile learning activities

The challenge of defining teachers’ roles in outdoor field activities has been observed in all three case studies. Common to these studies is a pronounced leaning towards student-centred learning. However, the challenge of defining teachers' roles was not raised because it is generally difficult to motivate and define such a role in a student-centred learning approach, largely because of the complexity of scaffold distribution and the limitations that emerge in outdoor contexts.

One of the questions raised in the case studies was: how do we define the teacher's role to complement or enhance other distributed scaffolds such as mobile technology, collaborative scaffolding, and activity structures, in order to coordinate a scaffolding system that maximizes the chance of students' needs being met? And, more importantly, how do teachers coordinate distributed scaffolds in a physical context where possibilities for communication and interaction between students and teachers are limited?

The complexity of the teacher’s role was most accentuated when the studies were scaled up, going from 6 students and two teachers in Case 1, to 21 students and two teachers in Case 2, and further to 30 students and two teachers in Case 3. In the first study, reported in Article II, we observed that, in the outdoor activities, teachers were more available to the students, had the chance to monitor the activities closely, and could proactively act and intervene in the field. Being continuously present in the background, and intervening only when judged to be necessary, the teachers could, for example, provide adapted feedback, initiate students’ reflections, regulate students’ collaboration, and scaffold problem-solving during breakdowns. The opportunity for teacher scaffolding of this kind was, because of the larger number of student groups and greater physical distance between teachers and students, considerably more limited in Case Studies 2 and 3. Because of pragmatic considerations, in Case Studies 1 and 2, the teacher’s role in the outdoor activities had to be redefined to include emphasis on providing scaffolding when called for by the students. This was at the expense of being able to continually monitor the activities and intervene...
with a richer and adapted scaffolding, and meant that students' scaffolding needs were met to a lesser extent.

As a consequence of the more limited teacher role, the findings reported in Articles 2, 3, and 4 clearly showed that students' scaffolding needs were not satisfactorily met in the outdoor activities. Furthermore, the findings obtained in Article 4 demonstrated that students, in the absence of a teacher regulating the activities, pursued non-intended objects, resulting in a mix of tensions in their activities that were unsolvable by the students.

Physical context

The physical context of learning plays an important role. The traditional classroom context is a rather controlled and planned environment with a limited spatial extension. Thus, the classroom context affords social interaction to an extent which an outdoor context might not. Moreover, outdoor contexts are often 'wild' in the sense that they are unorganized for learning and learners are exposed to an overflow of unfiltered stimuli. For that reason, we found it beneficial to arrange the outdoor contexts in order to scaffold the students. We physically demarcated designated areas in which the students were supposed to do their tasks, and QR tags were put on relevant species. What we achieved through this physical organization of the outdoor context was a scaffolding structure that directed the students towards the relevant learning objects.

Technology

Mobile technology can mediate and scaffold various processes and interactions. In the case studies presented in this thesis, we utilized mobile technology to scaffold students' interactions with the teacher, other students, the tasks, and the physical context (see Figure 16). For each of these categories of interaction various challenges and considerations were identified.
Student interaction with other students
In Article 1, I have strongly indicated that it is essential, on the one hand, to carefully examine what type of learning and collaborative opportunities mobile technology can open up so that collaborative mobile learning activities can be planned accordingly. It is crucial to negotiate with designers and developers the technical configuration of devices and functionality that predetermine the dynamics of learners’ collaboration. Essentially, we have to ask ourselves how the configuration and the distribution of the mobile technology empower learners and what that entails in terms of accessibility to essential learning processes and student agency.

Student interaction with teachers
In Case Studies 2 and 3, mobile technology was utilized in order to support interactions between students and teachers in outdoor activities. More specifically, the students could, when in need of assistance, use a common pad in order to call the teacher, who primarily tried to solve the issue through direct phone communication and secondarily by going to the groups to solve the issue in situ. Certainly, phone calls connecting teachers with students who are some way away will not harness the scaffolding capacity of teachers; it is however one pragmatic alternative among several. However, more attention must be paid to how to facilitate teacher and student interaction through mobile technology, and how mobile technology could be utilized to offer monitoring functionalities for the teachers conducting learning activities outdoors.

Student interaction with the physical context and the learning objects:
The mobile technology was also utilized for supporting students’ interactions with the physical context. The findings obtained show how mobile technology scaffolded:
- the students in terms of highlighting critical features in the physical context
- collecting data in the physical contexts
- creating and transforming abstracted representations of the physical context.

Several challenges have been identified regarding the orchestration of students’ interaction with the physical context through mobile technology. One of those challenges concerns the construction and reading of texts on mobile devices. In Case Study 2, for instance, we constructed multimodal texts that provided information about the species investigated by the students. These texts also directed the students’ attention towards the critical features of the physical learning objects (i.e. the species). The findings demonstrated that students who read and utilized the texts performed significantly better than those who did not. Unfortunately, a large number of students did not read the texts to the extent we had wished for. The reasons for that are many, and a limited screen may be one of them. In either case, this raised the following questions: how augmented information should be utilized for students’ interaction with context and how digital texts should be constructed to facilitate reading.

**Student interaction with the tasks**

In all three case studies mobile devices were also used to scaffold in terms of providing task instructions/structure and task feedback to the students. The findings indicate that the provision of task instructions by mobile technology was positive in general, albeit not completely unproblematic. In the learning activities, sometimes students followed the task instructions mechanically and unreflectively. This raises the question whether an overly pre-determined task structure provided by mobile technology prevents students from constructing their own actions and thus restricts flexibility and autonomy in terms of re-designing the task according to their perceived needs and curiosity.

Furthermore, in Article 4, the findings obtained showed students’ non-intended instrumentalization of the mobile technology. In the absence of a teacher regulating the activities, the students tended to use the mobile technology in non-intended ways in order to complete the activities as quickly as possible. This probably constitutes the most critical challenge associated with design of learning technology, namely that students will always be able to instrumentalize technology in non-intended ways, and it should be taken into account in the orchestration of mobile learning activities.
Learning processes and tasks

Throughout the three studies we observed that students’ conceptual scaffolding needs are not met sufficiently in the outdoor activities, negatively affecting performance in post-tests. Thus, fewer learning gains have been demonstrated the more the outdoor tasks have demanded conceptual thinking. These results have encouraged us to avoid taking as a starting-point the design of outdoor mobile learning activities supportive on their own accord. Instead we recognize that a better approach rather may be to investigate how different learning processes can be distributed, sequenced, and orchestrated across contexts. Essentially, it is a matter of acknowledging the limitations and utilizing the affordances of different contexts and resources.

In terms of distributing learning processes, we have found it beneficial to design the tasks in terms of a learning sequence (Selander, 2008) that spans contexts consisting of an indoor introductory activity, an outdoors activity, and an indoor post-activity. The utilization of this kind of learning sequence allowed us to distribute learning processes in a manner that increased the likelihood that suitable scaffolding structures would be available to support these learning processes. More concretely, it meant that emphasis was put on providing procedural tasks in the outdoor activity, and providing conceptual tasks in the post-activities in which teachers could scaffold students’ conceptual learning processes. This also meant that students constructed concrete representations in the outdoor activities supported by mobile technology, which were transformed into abstract representations in the post-activity supported by other tools and resources such as computers.

Modes and representations

In all three case studies, different resources were offered to the students to direct their attention towards specific learning objects, to represent the learning objects for the students, or as means for the students to represent their understandings and meaning-making. Here, these particular resources are defined as modes in accordance with the social semiotic perspective of Selander and Kress (2010).

Different modes in the sequence of learning activities were used as means to scaffold the students, and in particular to scaffold students’ internalization and externalization processes. For instance, in Case Study 1, we offered multimodal task instructions and queues, and encouraged the students to externalize representations of their understandings and meaning-making from the field activity by drawing measurement plans, writing
texts, and holding discussions. In Case Studies 2 and 3, we offered students the chance to engage with the learning objects and internalize representations of the species and their characteristics through different modes: digital pictures, texts, and sensory-motoric engagement. Different modes were also accessible for externalization processes: text for summing up experiences, pictures to capture characteristics, and video for constructing representations of students' reasoning and reflections regarding their experiences of the species.

Expanding a learning design sequence into a model for orchestrating scaffolding mobile-supported field trip activities

The above-mentioned scaffolding resources/aspects were identified as being of importance when formal mobile learning activities were orchestrated. However, in order to reap the benefits of the scaffolding resources and optimize supportive learning experiences, a productive coordination and management of the workflow is required. Quite early on in the research, the learning design sequence model of Selander (2008) was recognized as a good departure point (see Article 2). In a sense, the collected research work of this thesis can be viewed as a process of adapting the learning design sequence model to formal mobile learning settings, and as a process of producing findings that expand the learning design sequence model into a model for orchestrating formal mobile learning activities.

The learning design sequence model constitutes a good temporal structure for a workflow, and allows for useful decomposition of activities within the frame of a sequence of activities. Furthermore, the learning design sequence model also provides, for mobile learning scenarios, an applicable theoretical basis delineating, on a general level, fundamental learning processes in formal education. The underlying general assumption of the model, epistemologically in line with socio-cultural views on learning, is that we learn through different modalities in scaffolded tool-mediated activities in which we form and transform representations that are reflected upon and discussed on a social plane. A description of learning at this granularity level allows us to use the model to understand a variety of formal mobile learning activities in which learning in - and from - the physical context is of importance, ranging from situated problem-based learning scenarios such as the one in Case Study 1 to inquiry-based learning activities such as those in Case Studies 2 and 3. Indeed, in all three case studies the learning could be described as a transformation process in which learners, through tool-mediated interactions with the physical con-
text, and through different modes, transform their concrete outdoor experiences into representations that are further transformed, developed, and reflected upon in a classroom context.

Thus, in an attempt to construct a model for orchestrating mobile learning activities, I have departed from the learning design sequence model and added expansions based on the findings of the included research articles. The expansions are twofold; first I have described the setting in Selander’s model (2008) as a separate unit, and second I have integrated the scaffolding aspects discussed in the first part of Chapter 6 (see Figure 17).
As can be seen, the transformations units are central in the orchestration model, delineating a sequence of fundamental learning processes that need to be scaffolded. The six scaffolding levels (including modes as a level), on the other hand, delineate how each transformation unit in the sequence could be supported in order to meet students’ scaffolding needs.

The three units in the orchestration model

The Setting unit: when planning this unit, the designer is encouraged to reflect upon how the students can best be prepared in accordance with the needs of the subsequent stages in the learning sequence. This entails consideration of the relevance of the learning objectives within the frame of the curriculum and available resources, how tasks are introduced, how students are familiarized with the technology to be used, and how students are prepared with prerequisite subject knowledge, etc.

The Primary transformation unit: as Selander (2008) explains, this unit entails the interpretation of the task and the setting, and the process of transformation and formation of knowledge. In the case studies of this thesis, the primary transformation unit has corresponded to the outdoor field activities supported by mobile technology. For the primary transformation unit, the designer is encouraged to adopt a holistic view of the whole learning sequence, paying attention to the preparations in the setting unit, and the follow-up activities in the secondary unit. Special consideration should be given to the scaffolding levels in the model in order to coordinate and maximize support provided to students in the primary transformation unit.

The Secondary transformation unit: this unit follows up and complements the activities in the primary transformation unit and has a particular focus on student reflections, analysis, formation and transformations of representations, presentation and discussion. As for the primary unit, the designer is encouraged to adopt a holistic view of the whole learning sequence, paying attention to the preparations in the setting unit and the activities in the primary unit. Special emphasis should be put on the scaffolding levels in the model in order to coordinate and maximize support provided to students in the secondary transformation unit.

The scaffolding levels in the orchestration model

The tasks and learning processes level encourage designers to reflect upon the following questions.
• What kind of tasks and what type of learning processes in terms of procedural and conceptual factors are relevant with regard to available resources and the other scaffolding levels?
• How should tasks and learning processes be distributed over the learning sequence and across contexts, taking the other scaffolding levels into account, for instance, the available tools, the context, collaborative/individual work, etc.?

The context level encourages designers to reflect upon the physical contexts in which learning is planned to occur, answering questions such as:

• How is the spatial organization of the spaces in which learning is planned to occur arranged?
• What are the possibilities for movements, communication, interactions, collaboration, etc.?
• What aspects of the physical contexts should be utilized and interacted with?
• What is the role of technology in interacting with context?
• What are the constraints of the physical contexts?
• How should tasks be distributed across context based on context constraints and possibilities?
• How should the context be arranged to scaffold student learning?

The modes level encourages designers to reflect upon the selection of relevant modes and their coordination by asking the following questions:

• Which are appropriate modes considering the tasks, available contexts, tools, the social levels (collaboration/individual), etc.?
• How are the modes sequenced, coordinated, and orchestrated in a meaningful manner?
• What are the constraints of relevant modes?

The social level encourages designers to reflect upon how the individual and collaborative learning processes should be scaffolded, balanced, and coordinated by asking the following questions:

• Which processes/tasks/activities are suitable for individual work and which ones for collaborative work?
• What are the available resources for scaffolding individual work versus collaborative work?
• How can the other scaffolding levels be utilized to support individual versus collaborative work?
• What are the constraints for individual versus collaborative work?
The technology level encourages designers to reflect upon how technology and tools should be utilized to support learning in the learning sequence by asking the following questions:

- How should technology be used to support the learning processes in the transformation units? More concretely, how should technology be utilized to support interaction with context, collaboration and individual work, teacher scaffolding, and multimodal learning?
- How do we deal with students’ non-intended instrumentalizations of mobile technology?
- What are the constraints for utilizing technology to support learning?
- What constraints does technology introduce?

The teacher level encourages designers to reflect upon the role or different roles of the teacher in the sequence of activities, answering to the following questions:

- How do we define the teacher role in order to complement or enhance other distributed scaffolds such as mobile technology, collaborative scaffolding, and activity structures, and to coordinate a scaffolding system that maximizes the possibilities that students’ needs will be met?
- How do teachers coordinate distributed scaffolds in a physical context where possibilities for communication and interaction between students and teachers are limited?
- What are the constraints on teacher scaffolding?

As can be seen, the transformation units and the scaffolding levels are all interdependent in the orchestration model, encouraging holistic reflection, planning, and coordination.

The orchestration model should primarily be understood as a practical design tool that outlines aspects to consider when scaffolded formal mobile learning activities are designed, and guides the orchestration of such activities, and secondarily as an evaluation tool. As a design tool, the orchestration model can encourage and guide the designer to reflect systematically upon the holistic coordination of multiple across-context learning activities mediated by multiple tools and media.

Using the model to evaluate orchestration of mobile learning activities

The orchestration model, besides being used as a design tool during the planning of learning activities, can also be used as an evaluation tool for holistic evaluation of how a sequence of mobile learning activities has been coordinated to take students' scaffolding needs into account. An example
of an evaluation can be seen in Figure 18, where the orchestration model has been used to describe the orchestration of the mVisible II study (Case Study 3). The descriptions of the scaffolding levels can be more elaborately described than in the example.

Figure 18. Using the orchestration model to describe the orchestration of mVisible I
Theoretically, mobile technologies promise to support formal learning in innovative ways. During these years when I have indulged myself in the exploration of the literature in the field of mobile learning I have also noted the existence of convincing empirical indications supporting the theoretical promises of mobile technology. However, the exploration of the literature has also given me the impression that the field, to some extent, demonstrates an uncritical and glorified view of mobile learning in formal educational settings. The existence of an overwhelming amount of explorative papers reporting on positive applications and findings seems to indicate, as Kirkwood and Price (2014) put it, that many researchers take for granted that technologies can enhance learning. Still speaking rather subjectively, I have the impression that many researchers, including myself, are sometimes driven by the desire to evidence the potential of mobile technology at the expense of an open and critical exploration. And from a psychological perspective, perhaps it is natural that researchers, who in the end are only human beings, are motivated by the idea that they are working with something important, innovative, and progressive.

However, if we in truth desire to make innovative, progressive, and sustainable contributions to education, I believe that we need to develop and adopt a more critical lens through which to look at formal mobile learning. Such a lens should be open to the fact that the realization of the potential of mobile learning may be associated with limitations, challenges, and problems: some are solvable, some costly to solve, and others unsolvable. Perhaps such a lens should also see the possibility that mobile learning cannot be a shortcut to good education.

It is against such a background that one of the aims of this thesis has been to develop and adopt the critical outlook which I believe impregnates my general research work, especially the later articles. I started out by critically asking what the challenges and constraints are for scaffolding students in outdoor mobile learning activities, considering the changed conditions for providing scaffolding outside the classroom walls. The investigation of that question has led me through a cross-case and article analysis to identify several scaffolding aspects, and associated challenges and constraints,
which need to be considered when formal mobile learning scenarios are orchestrated.

The identified orchestration aspects, based on empirical data collected in three case studies, constitute the theoretical contribution of this thesis. It is my opinion that they contribute both to theories on orchestration and to a richer understanding of conditions for formal outdoor mobile learning. This understanding of course entails the aforementioned critical perspective. After all, several important challenges have been identified, amongst which some are difficult or costly to solve. For instance, despite efforts to provide and orchestrate scaffolding through different means, we observed that students’ scaffolding needs are not met appropriately in student-centred mobile learning activities. The research work has also demonstrated that collaborative scaffolding between peers correlates negatively with performance, largely because of the spread of misconceptions and incomplete and disorganized knowledge between students. These conclusions corroborate Kirschner et al.’s (2006) criticism of instructional methods with minimum guidance, and their large body of experiments provides evidence for the negative consequences of inadequately guided science instruction, at all age levels and across a variety of science and maths content. Thus, student-centred mobile learning raises a great challenge for researchers and designers, who need to find a role for the teachers and the students in the activity systems that enables agency for both of them and ensures that specific pedagogical objectives are achieved.

The orchestration model, as a second (practical) contribution of this thesis, relates to the identified constraints and challenges associated with scaffolding students in mobile learning situations. As a practical design and evaluation tool, the model should not be understood as a recipe for successful orchestration, but rather as a support for designers (teachers or researchers) to reflect systematically and holistically on relevant aspects when orchestrating mobile learning activities. Although the model certainly needs to be further tested and its usability and generalizability further evaluated, it does stand on reasonably solid ground. The orchestration model is after all based on empirical findings obtained in three case studies, and it is partly based on Selander’s well-tested learning design sequence model (Kjällander, 2011; Bundsgaard & Hansen, 2011; Selander, 2007, 2008).

The developed learning activity design framework (LEAD framework) described in Article 5 constitutes the third (methodological) contribution of this thesis. The LEAD framework draws inspiration from design-based research and interaction design with a focus on providing a stronger methodological approach for research and sustainable innovations for
everyday classroom use by learners and teachers. In my opinion, the LEAD framework addresses several challenges associated with the enterprise of designing innovative and sustainable learning activities such as informing design with learning theories, grounding it in sound pedagogical principles, building design on current pedagogical practices, and facilitating the use of technology with robust and usable mobile devices.

The LEAD framework is founded on a conceptualization of a design process that has matured through design experiences of four different studies over a period of five years. The most mature version of the framework has been tested in the mVisible II study. However, as with the orchestration model, the usability, generalizability, and validity of the LEAD framework certainly need to be verified through further tests and evaluations.

The particular utilization of and reflections on the second-generation cultural-historical activity theory for studying mobile learning constitutes the fourth (methodological) contribution of this thesis (see Articles 1 and 4).

**Future work**

Some possible future research steps were indicated in the above discussion regarding further testing, evaluation, and refinement of the orchestration model and the design framework. However, there are of course other possible research directions that could be pursued.

In all case studies presented in this thesis, the researchers in the projects provided the mobile technologies and developed the software systems. These software systems are not available on the market and are probably too complex and costly for teachers to replicate. Thus, one interesting way forward could be to study teachers’ orchestration of mobile learning activities with available technological resources, and perhaps without researchers informing them. Such a direction raises several interesting questions such as: 1) how is mobile learning organically adopted in schools? 2) how do teachers assemble and utilize available technologies and software when orchestrating mobile learning activities? and finally 3) what are the challenges for teachers orchestrating their own mobile learning activities with available resources?
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Appendix 1: Letter of consent

mVisible is a research project where small groups of students use Android phones and tablets outside the classroom to explore a natural phenomenon. In mVisible the students are to identify and learn the characteristics of species of plants and trees, and to count the number of trees for each species to learn what kind of forest they are working in. Plants and trees are tagged with QR codes, and when scanned with a mobile phone the code gives additional information on the characteristics of each species. A pie chart created on the Android tablet can then be used to see how the different species are distributed.

Within the project we plan to perform a study in collaboration with teachers at Rösjöskolan in which we want to study the use of mobile phones and specific applications in the design of a biology task outdoors. The study is a follow-up of a previous study, which was held at Rösjöskolan.

The students who participate in the study will take part of activities both indoors and outdoors where they work with concepts in biology. In the study, we will collect information using video cameras (video and audio). In addition to the guidelines and principles that the school has for the handling of various types of digital information, we will follow a number of ethical principles in the implementation of this study. In the formulation of this letter, we respect one of these important principles: the principle of consent to participate in the study.

Participation in the study is voluntary, and if a student would want to withdraw their participation, they can do so at any time without suffering any negative consequences for the student. We will store the data collected in such a way that it is impossible for outsiders to access. We will not use this data in any way other than for scientific research (writing and publishing of research articles). This means that we could choose to use pictures of activities in a research publication or presentation.

We are working on the project: Researcher 1, 2, ...Teacher 1, 2, ...

I hereby approve that my child participates in this study: Parent 1, 2

(Translation by Johan Eliasson).
Included Articles