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RESEARCH

A Learning Activity Design Framework for Supporting Mobile Learning

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This article introduces 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.

Keywords: Design-based research; Interaction design; Mobile learning; Methodology

Introduction

Mobile learning as a research field can be traced back to the 1990s (Soloway et al, 1999). The rapid adoption and widespread use of mobile devices in society, combined with the fact that these devices incorporate functions such as camera, video camera, radio, computer and telephone has certainly been a catalyst for ideas about the use of ubiquitous devices in education (cf. Laurillard, 2009). Thanks to specific advantages such as portability, wireless connection, long battery life, integration with web 2.0 services for user-generated content and collaboration and sharing, mobile technologies have become omnipresent in discourses about progression, innovation and modernism. Interestingly, these last in part summarize what the educational system worldwide is desperately seeking.

Research on mobile learning is one of the most promising research fields within technology-enhanced learning (Johnson et al, 2014). Since the late 1990s considerable research in the field of mobile learning has attracted interest in investigating the use of mobile technologies in schools for educational purposes. Schools in Europe, however, generally do not welcome mobile devices in the classroom. Recent studies have shown that most of the innovations related to the use of ICT in schools have not impacted on pedagogical or school development (Buckingham & Willett, 2006; Coiro et al, 2008; Snyder et al, 2010). Consequently, mobile technologies have not yet sparked the knowledge revolution in schools expected by the telecommunications industry. On the contrary, mobile technologies remain extensively used outside the frontiers of formal education (Pachler et al, 2010). The reasons for this are many and varied. In this paper we choose to concentrate on what we perceive as prevalent methodological weakness in the development of innovative educational interventions with mobile technologies. The methodological approaches applied in the field of mobile learning are generally centred on design-based research, aiming to use formative research to test and refine educational practices based on theoretical principles derived from educational research (Collins et al, 2004). However, according to our own observations, and as noted by Looi and Wang (2014), there is a gap in mobile learning research which is characterized by an absence of articles providing meta-reflections on the use of design-based research methodology for mobile learning and methodological frameworks for designing sustainable mobile learning activities.

Therefore, the questions that motivated the work presented in this paper are: 1) *what are the criteria's for a sustainable and usable design-based research framework for formal mobile learning?* and 2) *what kind of design framework can meet those criteria's?* We are particularly interested in which methodological tools researchers use in the field of mobile learning to design their interventions

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and which tools actually help them to envisage the design process from the early phases to the latter phases of evaluation.

The paper is organized as follows. The background section makes a case for improving the methodological approach to mobile learning and provides a theoretical background drawn from design-based research (DBR) and interaction design (ID) for learning activities. The subsequent section introduces the learning activity design (LEAD) framework as an answer to the posed research questions. The article concludes with a discussion of the next steps in the further development of LEAD.

Background

National and European funders have made significant investments in research on education in an attempt to find out what kind of progression, innovation and modernization the introduction of mobile technologies can offer schools and other educational providers. From a review of some of the most salient European research projects we distinguish the following current patterns.

1. Technology-driven view in the field of mobile learning, providing optimistic views of changes needed for the incorporation of mobile devices in learning activities and teaching practices.
2. Evaluation of learning outcomes mostly focusing on learners' motivation; little is still known about the teaching practices and learning processes which are unfolded in the interaction of mobile technologies across educational contexts (Wingkvist & Ericsson, 2009; Sharples, 2009).
3. A multiplicity of research studies are conducted in schools without showing clear pedagogical foundations or with limited information about designing conditions for learning to develop both in situ and trans-educational contexts (Kukulska-Hulme et al, 2011).
4. A strong interest in designing mobile technologies in comparison with concern to design learning activities integrating the use of mobile technologies (Traxler & Kukulska-Hulme, 2005).

These patterns show us how learning with mobile technologies has been conceptualized in contexts such as schools, museums and field trips. Research efforts in the field of mobile learning have so far struggled with methodological and practical questions related to the methods and frameworks necessary for putting into design pedagogically sound educational activities. Design experiments are quite common in the field of mobile learning. However, a large proportion of the studies have habitually been enacted in a way that leaves much to be desired. On the one hand, many questionable DBR approaches have been excessively techno-centric, guided by a strong interest in designing mobile technologies instead of an interest in 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).

Putting it differently, these research efforts have in their endeavours overlooked methodological and practical questions related to the methods and frameworks necessary for putting into practice, on the one hand, design-sustainable educational activities in cooperation with practitioners and learners and, on the other hand, for conducting relevant research studies about the usability of the designs implemented as well as their feasibility and sustainability. As Walker (2007) highlighted, designing for mobile learning remains a critical challenge for research and practice.

For instance, Shavelson et al (2003) and Dede (2005) have argued that having a strong technological determinist design approach that uses predetermined solutions to solve educational problems could lead to under-conceptualized research. Further, DiSessa and Cobb (2004) have argued that design-based research lacks a strong theoretical foundation and does not attempt to generate findings for the refinement of theory. These methodological issues are echoed in the field of interaction design. Greenberg and Buxton (2008), for example, contend that the field has a tendency to focus on getting the design right in terms of research, neglecting the need to get the right design for the product or service outside the research context. The crux of their argument is that research practice favours fewer iterations of design ideas by focusing on problems and risks instead of using design synthesis to generate different ideas iteratively to solve the design problem. These methods need to guide scientific knowledge and everyday use by learners, teachers and the structures that support education (Ejersbo et al, 2008).

Design-Based Research (DBR)

DBR embodies an epistemology that is rooted in pragmatism (Romme 2003; Wicks & Freeman, 1998) with an agenda that is change-oriented, functionally-organized, value-laden, representation-aware and context-sensitive. The methods are highly interventionist, situated, iterative and humble (Mor & Winters, 2007). 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 been 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 the 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 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 to a greater extent that research outputs have a bearing on educational practices. DBR envisions that researchers, practitioners and learners/users work together with the goal of producing or facilitating a meaningful change in the 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); design research (Cobb et al, 2003; Collins et al, 2004); development research (van den Akker, 1999); developmental research (Richey & Klein, 2005); and formative research (Reigeluth and Frick, 1999). In this respect, DBR entails a series of approaches intended to produce new theories, practices and artefacts that account for learning and teaching in educational practices. Central to DBR is design, however; design considered as a membrane between research and practice (Spikol, 2010).

Learner-centred design

An early bridge between DBR and ID was learner-centred design, developed by Soloway et al (1994). These authors put learner needs into focus by addressing the conceptual distance between the learner and the computer. LCD uses this conceptual distance between the learner and the computer, as defined by Norman (2002), to design software where the focus is not on usability but on learning. Luchini et al (2004) formulated the goals of LCD as tools that need to address the conceptual distance, 'the gulf of expertise', that lies between the novice and the developed understanding or expertise embodied by a more capable peer. More recently, Stolterman (2008) and Rogers (2009) argued that the characteristics of interaction design have grown beyond its role of just supporting theoretical approaches, methods and tools. They present the case for adopting new design approaches that have intellectual roots in other academic areas such as science, engineering, social sciences, humanities and the traditional art and design disciplines. Dede (2004) argued for the importance of DBR, but highlighted the challenges of applying it well. He pointed out that creative designers and rigorous scholars have limited overlap and even theory-based design does not follow recipes, but rather draws heavily on imagination and instinct. Additionally, technology-driven research that starts with a 'solution' and seeks educational problems to which it can be applied provides a dubious basis for DBR in the case of many projects.

Integrative Learning Design Framework (ILD)

The Integrative Learning Design framework (ILD) of Bannan-Ritland (2003) is one of the coherent frameworks developed particularly for design-based educational research. The main goal and characteristics of the ILD framework (see **Figure 1**) are, according to Bannan-Ritland (2003), to 'position design research as a socially constructed, contextualized process for producing educationally effective interventions with a high likelihood of being used in practice', and to 'organize a trajectory from early stage research to evaluation of broader impacts' (p. 21). Furthermore, the stated goal of the ILD framework is to provide a broad context within which to map the design-based research processes, and explicitly to be a tool for engineering constructive and effective learning environments that allow teachers and learners to make propositions and to make learning and teaching actionable. Another merit of the ILD framework is that it draws from several design traditions; namely, instructional design, product design, usage-centred designs, diffusion and innovations, as well as established educational research methodologies. A framework of this kind is, to a large extent, aligned with what we perceive to be absent in the field of mobile learning, and how we consider that design-based research within mobile learning should be conducted. Thus, the ILD framework is held to be a good point of departure.

Participatory methodology for interdisciplinary design in TEL

For Mor et al (2012), one of the causes of the weakness prevalent in TEL methodologies is related to the lack of true interdisciplinary design processes in the field of education. Existing learning design frameworks tend to be very concrete. According to Mor et al (2012), the existing frameworks 'are powerful for rapid production of quality materials once the design is specified, but weak in supporting a higher-level discussion' (p. 2). Putting the problem in these terms grounds his methodology in a design-based approach originally proposed by Alexander et al (1977). Specifically, Mor builds an IDR approach based on 'design patterns' constituting a common language between all those involved in the development of TEL environments. The IDR methodology supports participatory development of software applications by employing design patterns as a communicational framework to support an inclusive and interdisciplinary community of teachers, learners, researchers and designers/producers of technology and/or content.

Mor's approach presents design patterns as high-level roadmaps for design, questioning the expert-novice dichotomy and challenging the 'lone-designers' paradigm. A design pattern is considered as:

> 'a semi-structured description of an expert's method for solving a recurrent problem, which includes a description of the problem itself and the context in which the method is applicable, but does not include directives which bind the solutions to unique circumstances' (Mor & Winters, 2007: p. 66).

Design patterns are also seen as analytical and communicative tools. Analytical tools describe design situations and solutions and communicative tools enable different communities to discuss design issues and solutions. In this sense, patterns are here considered as a potential solution to the problem of the lack of cumulatively built understanding within the TEL field. According to Mor and Winters (2007), the design cycle provides a lens through which to view interdisciplinary practice; the suggestion is that at each stage of the cycle the emerging patterns capture various facets of design knowledge within the team.

The need for pragmatic methodological tools

From the multiple variants of DBR, we have chosen to focus specifically on the Integrative Learning Design framework (ILD) suggested by Bannan-Ritland in 2003 and 'participatory methodology for interdisciplinary design in TEL' (IDR) suggested by Mor and Winters (2007). These versions of DBR are chosen because they provide methodologies that are often used to conduct research in the field of mobile learning. Likewise, these methodological frameworks represent different degrees of granularity in conceptualizing the design-based research process. The two methodological variants of DBR suggested by Mor and Winters (2007) and Bannan-Ritland (2003) are seen here as examples of two types of methodological reasoning that can be applied to support our research and design goals with DBR; IDR suggests a reasoning based on pragmatic tools able to help researchers to have high-level discussions with other stakeholders and ILD suggests a reasoning based on conceptual tools able to help researchers to have an integrative view of the different stages involved in the design-based research process.

Following Confrey (2006), we argue that the main contribution of design studies is the articulation of domain-specific guidance illuminating conceptual learning 'corridors', and that the aim of design experiments is to articulate two related concepts: a conceptual corridor and a conceptual trajectory. He describes the theoretical construct of a conceptual corridor as a possible space which must be navigated successfully to learn conceptual content. The conceptual learning trajectories on the other hand represent the particular learning trajectories students will traverse during a learning activity. Confrey (2006) further states that the goal of design experiments is to model the conceptual corridor and gives a description of all the possible conceptual trajectories. Thus, effective instruction depends on how well that corridor is engineered so that the likelihood of fruitful learning trajectories is increased. In this light, on a meta-level, the ILD framework can be used to roughly model the conceptual corridor of the design process (i.e. design the design process), with a description of the phases and data-streams needed, but it lacks the detailed information needed specifically to delineate the fruitful trajectories of the design process, that in turn leads to the modelling of a fruitful learning corridor with fruitful learning trajectories (see **Figure 2**). For instance, the framework does not demarcate the roles of the multiple data-streams and actors and how they should be orchestrated to construct a successful design trajectory.

In general, too many questions are left for the designer to answer, resulting in a very broad design corridor and leaving out the necessary guidance on fruitful design trajectories. When elaborating on design-based research, Collins et al. (2004) argue that design experiments are developed as a way to carry out formative research to test and refine educational practices based on theoretical principles derived from previous research. The ILD framework unfortunately does not explicitly and concretely address which aspects of the designed innovation may be informed by principles drawn from learning theories or previous research. Nor does it address which aspects of the designed innovation may be informed by end-users such as teachers and students, and how computer science should contribute to the design of the innovation. Also, the ILD framework puts forward usability and adaptability as aims to be achieved but leaves out how the different data-streams should be utilized in order to inform and produce usability and adaptability. More importantly, it also leaves out how the different data-streams could be combined during the different phases of the design process in order to create synergies amongst them and decrease the risk of tensions and conflicts.

Therefore, although the ILD framework is certainly a good point of departure, it does not constitute a fully practical design framework because of the aforementioned gaps and the high abstraction level on which it operates. A framework is needed that more concretely outlines how a fruitful design corridor could be constructed in a multidisciplinary design approach, delineating the role of different data-streams during each phase in the design process and more explicitly addressing usability and adaptability. With regard to the IDR approach of

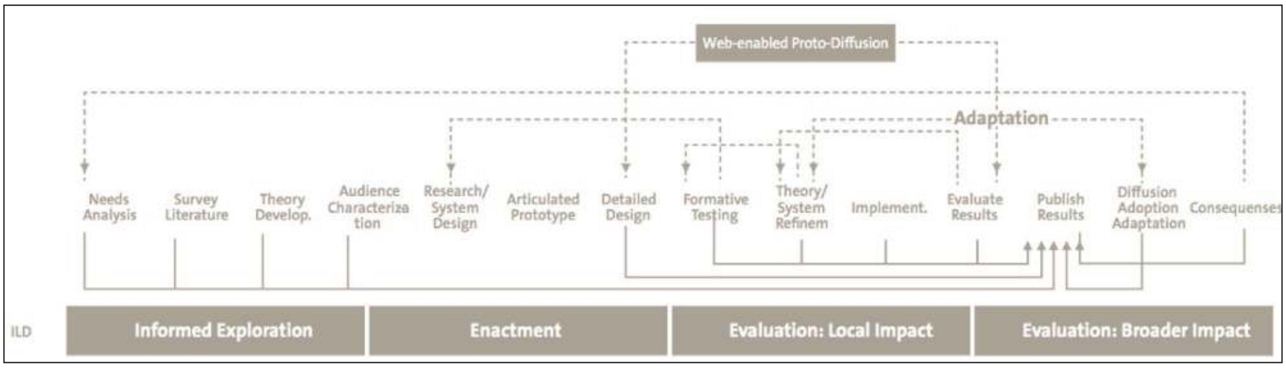

Figure 1: The Integrative Learning Design framework (adapted from Van den akker et al., 2006).

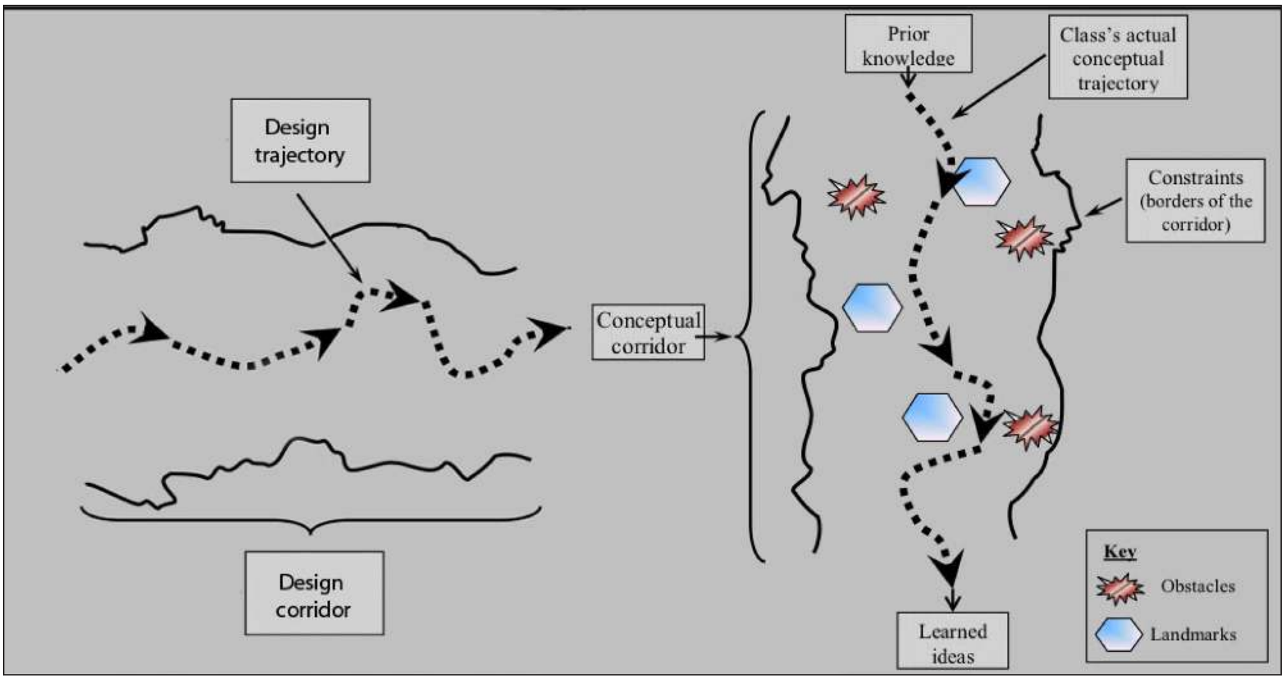

Figure 2: The design corridor and design trajectory leading to a fruitful learning corridor and learning trajectory (Confrey, 2006).

Mor and Winters (2007), it is claimed that design patterns serve as common language and that the employment of design patterns as a communicational framework supports inclusive, interdisciplinary and participatory design of TEL. Certainly, we believe that design patterns may have that function. However, design patterns as defined by Mor and Winters (2007) provide a description of quite specific recurrent problems and their solutions, and do not serve as well as a general framework that describes a whole design process. In other words, the design patterns of Mor and Winters (2007) do not outline the design of the design process, albeit they could be part of a design process and framework. The design-research cycle suggested by Mor and Winters (2007) is closer to our envisioned framework, but, as it clearly operates on a high abstraction level, it does not meet the defined criteria.

Taking into account the integrative aspects of learning suggested by Bannan-Ritland (2003) and the pragmatic tools proposed by Mor and Winters (2007) in relation to our own past design experiences (Nouri et al., 2011; Eliasson et al., 2012; Nouri et al., 2013; Nouri et al., 2014), we offer the following set of criteria for a design framework for mobile learning.

- Organizing a trajectory from early stage research to evaluation of broader impacts.
- Taking account of educational foundations, usability and sustainability.
- Taking account of multiple data-streams and multiple actors in the design process (a design informed by several streams of input including learning theories). Taking account of a multidisciplinary design approach.
- Delineating the roles of these data-streams and actors such as researchers, teachers and students during each phase in the design process.
- Specifying design and engineering aspects of learning activities.

The ILD framework certainly fulfils many of these criteria. The framework's merit is indeed, besides the fact that it draws upon several successful design traditions and is particularly developed for educational research, that it organizes a trajectory from early stage research to evaluation of broader impacts and takes account of sustainability and multiple data-streams. With the relatively high abstraction level of the ILD framework, flexibility is also implied by the presentation of a broad and general trajectory of a design process that designers and researchers can tailor to their own requirements. Despite this, and because of the negative implications of the abstraction level, the ILD framework is unfortunately not sufficiently concrete to constitute a practical tool for designing technology-enhanced learning activities.

In the next section, we present what we argue is a framework that meets the criteria, the Learning Activity Design framework, partly drawing upon the ILD framework of Bannan-Ritland (2003), the ILD approach of Mor and Winters (2007), design-based research literature, our design experiences and interaction design methodology.

The learning activity design framework

The Learning Activity Design (LEAD) framework presented here incorporates elements from both Bannan-Ritland (2003) and Mor and Winters (2007). It is grounded in past work reported in the following publications: Nouri, J., Cerratto-Pargman, T., Eliasson, J., Ramberg, R. (2011); Eliasson, J., Knutsson, O., Nouri, J., Karlsson, O., Ramberg, R. and Cerratto-Pargman, T. (2012); Nouri, Cerratto-Pargman & Zetali, 2013); Nouri, Cerratto- Pargman, Rossitto, Ramberg, 2014.

It consists of the following phases: 1. describing current learning and teaching practices, 2. envisioning pedagogical practice, 3. prototyping pedagogical practices and envisioned prototypes, 4. implementing mobile learning activities and 5. evaluating mobile learning activities (see **Figure 3**).

Each one of the phases of the LEAD framework is described and exemplified in the presentation of the 'mVisible II project' one of the mobile learning projects we have lately conducted in close cooperation with a primary school in the north of Stockholm, Sweden. The mVisible II project was a research project where seven small groups of students in the fifth grade, guided by two teachers, interacted with smartphones and pads while they were in the woods exploring various species of plants and trees and their biotopes. The children were working in groups of three within two school subjects, natural sciences and mathematics. One of the research goals motivating the work conducted within the mVisible II project was to study the role of mobile devices in the process of making abstract relations such as species biotopes and tree distribution visible.

Four areas of research informed the design of the mVisible II project: 1. previous mobile learning research (as presented above), 2. pedagogy and didactics and more specifically inquiry-based learning, 3. participatory design together with teachers and students and 4. interaction design.

The design process, including prototyping and field trials, was realized during spring 2011 and the main study was done during the months of May and June 2011. A main activity in the project was learners' identification, reading and analysis of digital information about specific plants and trees. In this context, plants and trees, previously selected, were tagged with QR codes so that when they were scanned with a mobile phone the code provided learners with detailed information about the salient characteristics of each species. Besides the mobile phones, the learners used a tablet that was located in the woods and provided a pie chart displaying the distribution of the different species identified by the children in situ.

A specific characteristic of the LEAD framework is its focus on usability and sustainability issues with respect to the introduction of technology-based educational innovations. Issues about usability concerned in particular the design of the interaction between the students, the mobile devices and the objects of the study distributed in the woods. Issues about sustainability concerned the introduction of innovative mobile learning activities in the school that were aligned with current pedagogical practices.

Phases of the LEAD framework

Phase 1: Describing current learning and teaching practices

General Goal: This phase requires designers and researchers to understand how learning and teaching practices are organized in a specific educational institution and to identify both challenges and opportunities of current practices.

Methodological tools: the tools used to collect and document data during this first phase were mainly future workshops conducted with students (Greenbaum & Kyng, 1991), and interviews conducted with the teachers. The future workshops were a structured brainstorming session consisting of three stages: the critique, the fantasy and the implementation. During the first phase of the process we worked with the critique stage, which aims at understanding current learning activities from the students' perspective.

The first phase consists of two main stages. The first stage is a preparation stage, including presentation of the project, inviting the students to generate representations of current learning activities, getting an understanding of the students' motivation. The first stage aims at preparing the students to elicit their representations concerning their current learning practices. The second stage is called the critique stage and it aims at enabling the students to reflect on their representations of current practices in general and on the problems and difficulties they encounter with these practices in particular.

Preparation stage

Three main activities are conducted during the preparation stage: presenting the project, inviting the students to generate representations of their current learning activities and getting an understanding of students' motivation.

Presenting the project

The aim is to create a common frame to which the students relate in their discussions in order to trigger ideas in a trajectory towards our main goals for innovation. For instance, in the mVisible projects our design intervention was presented as a study investigating how 'everyday technology such as mobile phones and pads can be used in natural science and mathematics education, with the overall aim of making mathematics and natural science education more concrete, simpler and more fun'.

Inviting the students to generate representations of current learning activities

The main goal of this stage is for students to generate representations of how learning activities from their perspective unfold in the classroom. Setting up an activity with the students that allow them to share their thoughts and representations of what and how they learn means they start unpacking experiences of the different activities they are involved in during natural science and mathematics education. For example, in the mVisible projects, we wanted to know how the students studied natural science and mathematics, focusing on the different activities involved such as calculating, reading, writing and presenting to the class.

This stage is important in terms of giving students the opportunity to talk and thus reconstruct representations of their learning practices. Students' representations work as a point of departure for them during the critique and fantasy stages of the future workshop.

Getting an understanding of the students' motivation

This stage aims at drawing a picture of the students' interests and incentives. Knowledge of students' motivation is essential for the design of any systems they are

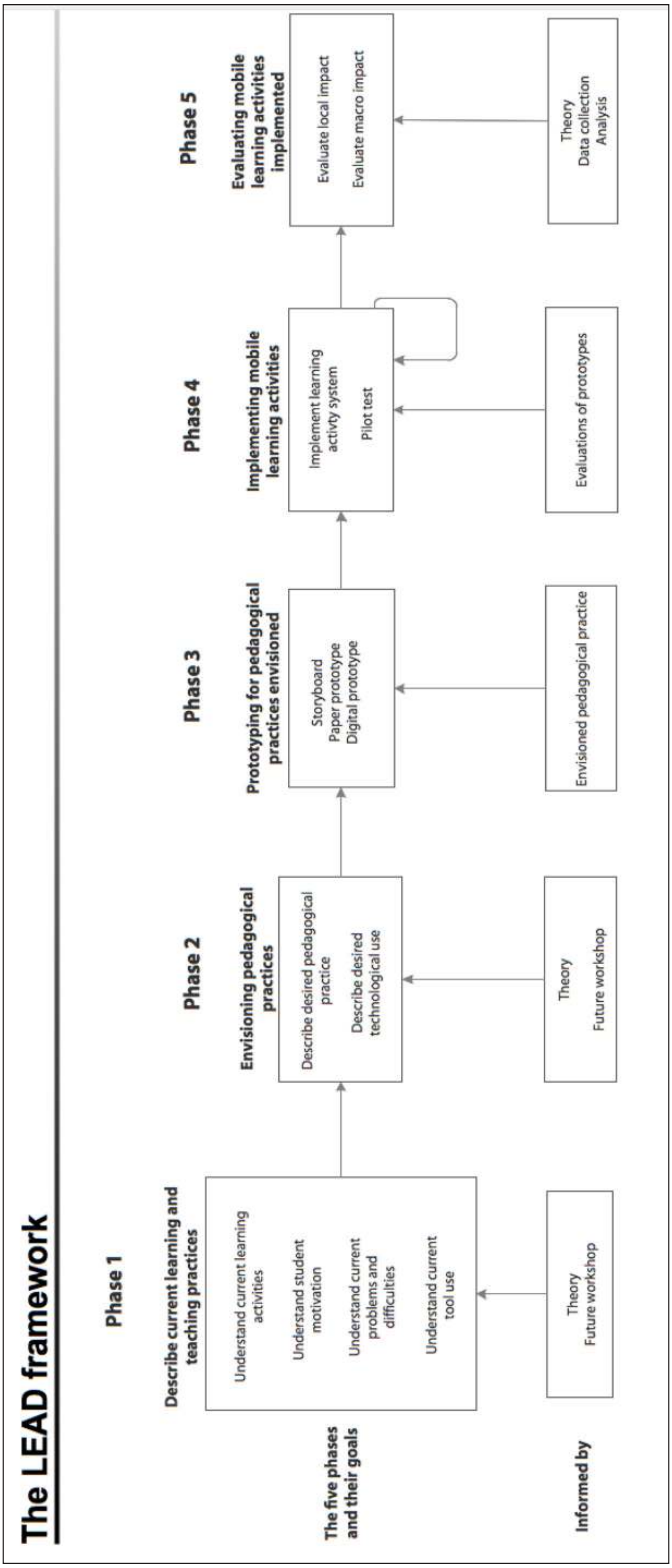

Figure 3: The five design phases of the LEAD framework.

intending to use. The outcome of this stage is twofold: students reflect upon what motivates them (which can be useful representations during the critique and fantasy phase), and researchers and designers get an understanding of their motivations.

One way to organize the students' work is to start a discussion regarding what motivates them in terms of content and practice.

Critique stage: problems and difficulties

In this stage the main focus is on the problems and difficulties students have with learning school subjects, such as natural science and mathematics in the mVisible projects. Knowing about students' problems and difficulties is central for the development of educational innovations connected to actual learning conditions and learners' needs. The stage can be organized through discussions with the students or through brainstorming sessions. Examples of questions discussed in the mVisible project are: what is difficult in mathematics? what is difficult in solving and presenting solutions to mathematics problems? what is difficult with natural science education?

The first phase is completed by conducting interviews with teachers and conducting a literature review of past educational research. The interviews aim at investigating teachers' experience of what students find difficult in selected subjects for the project. The literature review of past educational research investigates the difficulties and problems associated, for instance, with natural science and mathematics education.

Phase 2: Envisioning pedagogical practices

General Goal: this phase consists of generating visions for new pedagogical practices based on two input sources; theoretical frameworks within pedagogy and practical input from students' and teachers' visions. The theoretical knowledge provides the designers with a scientific grounded model for learning, and students' and teachers' input grounds the innovation in the actual working and learning conditions of the end-users. These two input streams may contradict each other or create tensions, which raises the question of what determines the end result if such tensions arise.

The goal of this phase is for researchers, designers and teachers to identify potential pedagogical practice. For instance, in the mVisible project the theoretical input came from the pedagogical framework 'inquiry-based learning'. Inquiry-based learning prototypically involves learner-centred and non-structured investigations that are based on students' own choice of questions and hypothesis, observations of phenomena, and the procedures involved in the inquiry process (Colburn, 2000; Edelson et al, 1999). In this context, more structured and guided inquiry activities are preferable if the intended students are young and lack experience of inquiry (Colburn, 2000). In the designs conducted with fifth-grade children we chose to a solid structure to guide the students through the inquiry-based mobile learning activity. More concretely, the desired pedagogical practice was conceived within the frame of inquiry-based learning and based on student-centred learning and a learning sequence consisting of proposing questions, observing the phenomena, collecting data and analysis of the data.

The practical input comes from two sources, namely interviews with the teachers and the fantasy stage of the future workshop with the students. Prior to the fantasy stage the students are 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 the mVisible project the fantasy phase ended with a summary whereby groups of students presented the visions they had written on post-it notes. The researchers clustered the collected students' visions in an affinity diagram (see **Figure 4**). After consultation with the teachers, one vision was chosen for further development.

Phase 3: Prototyping for pedagogical practices envisioned

The goal of this phase is to produce and examine a tangible prototype of the envisioned pedagogical practice developed together with students and teachers in phase 2 of the design process. Two prototypes, a paper prototype (see **Figure 5**) and a hi-fi prototype (see **Figure 6**), are developed and tested together with the students.

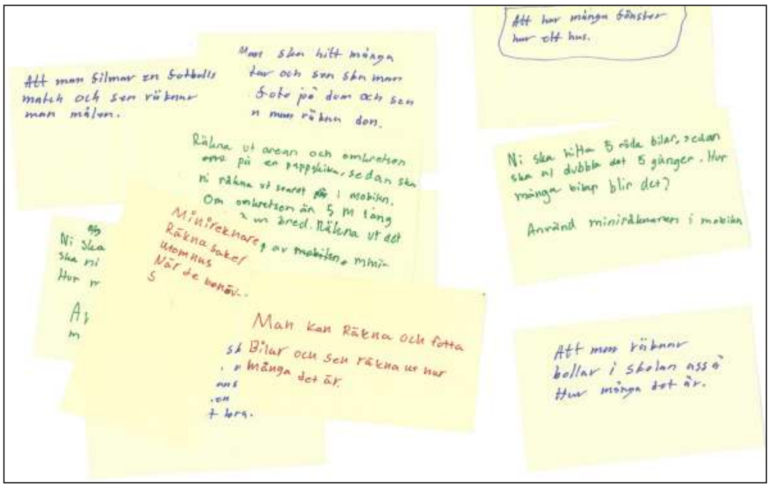

Figure 4: Students' visions clustered into an affinity diagram.

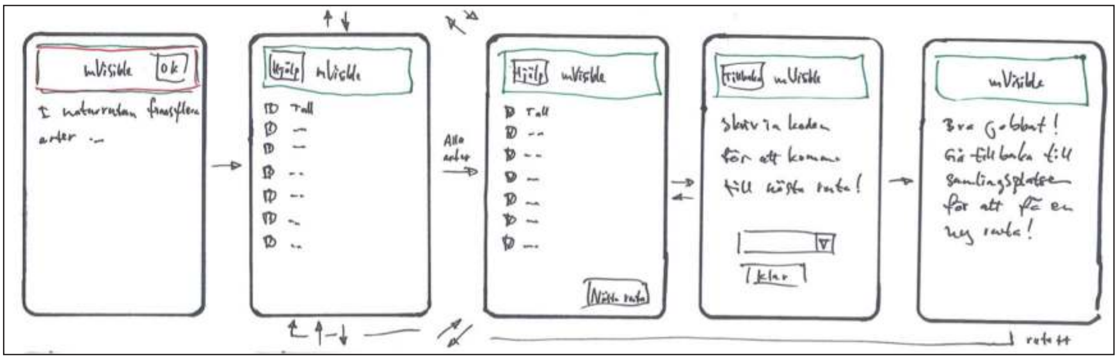

Figure 5: A paper prototype from the mVisible project.

Figure 6: A digital hi-fi prototype from the mVisible project.

The aim of generating the paper prototype first is to carefully examine the pedagogical sense of the core ideas that are present in the envisioned pedagogical practice chosen. To develop a complete hi-fi prototype first will inevitably turn the focus on technology and usability issues instead of prioritizing the pedagogical ones. In the mVisible project, the approach applied in the generation of the paper prototype test was to let one group of three students perform 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. 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 hi-fi prototype test, which was informed by the paper prototype test, was to let another group of three students go through the envisioned mobile learning activity, but unlike with the paper prototype this activity was conducted with the actual mobile devices and the designed software system.

After evaluation of both types of prototype it is important to create an inventory of identified obstacles and problems. For instance, in the mVisible 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, 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 may need to be defined or be better specified. The set of specified requirements informed the implementation phase.

Phase 4: Implementing mobile learning activities

The goal of this phase is 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 are interaction design, learning design and computer science.

From an interaction design perspective focus is put on enhancing the usability of the device; for instance, in terms of interaction with the interface and its features. Usability requirements can be elicited through an interaction analysis of prototype testing.

From a learning design perspective, focus is 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 is put on completing the software system and further aligning the technology with the learning activities, which concretely entails taking care of bugs and shortcomings encountered in the prototype tests, implementing reviewed tasks and taking account of collaboration scripts and scaffolding changes, along with the usability requirements.

For instance in the mVisible project, after implementation of the whole learning activity system, a pilot test was also planned and conducted. The idea was to let 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 evaluation phase in the LEAD framework consists of two components, namely one evaluation of the local impact and an evaluation of the broad impact. Our evaluations of the local impact comprise analysis of how well researchers' and designers' intervention satisfied the end-users and what educational and interactional effects the intervention had. These evaluations were based on the data collected in the studies comprising video, audio, interview and survey data. The evaluations of the mVisible I study also informed a second design iteration, the design of the mVisible II study.

Attempts to evaluate the broader impact have also been made in the mVisible projects, captured in (Nouri et al., 2014). Focus in this evaluation was put on the educational outcomes of the mobile learning activities and the orchestration cost in comparison with traditional learning methods. Certainly, an evaluation of this kind is not sufficient to delineate the broad impact of the learning invention, but it does tell us something about the likelihood of broader impacts in terms of integration of mobile technology in education. In order to examine the broader impact in greater depth, we think longitudinal studies are most appropriate for studying long-term integration of the technology as well as questions such as how teachers and students re-design the intervention and adopt it in new practices.

Discussion

From our own past design-based research experiences we are aware of some of the 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 by means of robust and usable mobile devices. As an attempt to address these challenges, in this paper we introduced a methodological framework (LEAD) within design-based research. The LEAD framework is a conceptualization of a mature design process based on our experiences of four different studies over a period of six years. The most mature version of the framework has been tested in the mVisible II project presented in this paper.

With respect to our own experiences with the framework, in relation to the defined evaluation criteria which we argued a design framework for mobile learning should fulfil, the following can be said. First, the LEAD framework could indeed organize a trajectory from early stage research to evaluation of broader impacts, as demonstrated in the five phases of the mVisible II design process. Second, through our multidisciplinary design approach, combining an interaction design perspective with the perspectives of learning design and computer science, and pointing to their roles and relations in different design phases, we managed to: 1) take account of educational foundations and usability, as demonstrated in (Nouri et al, 2014); and 2) as demonstrated in the description of the five phases, we managed to take account of multiple datastreams and multiple actors in the design process, and 3) delineate the roles of these data-streams and actors such as researchers, teachers and students during each phase in the design process.

This, combined with the granularity level of the framework, and in particular the concrete and detailed descriptions of the phases, culminated in what we consider to be a framework that is concrete enough for design and engineering of learning activities.

Yet some issues deserve more work and consideration. The first challenge we aspired to address concerned the sustainability of design-based research innovations. Although we believe that the LEAD work facilitates the construction of conditions for sustainability, such as through a participatory interaction design approach involving the endusers, the evaluations necessary for examining the broader impacts and focusing on how sustainable the LEAD innovations are have not been conducted. Another issue concerns the generalizability of the framework. The LEAD framework is based on our experiences of designing for a *particular target group*, namely primary school children, for *particular subjects* such as mathematics and natural science and for *particular pedagogical approaches* such as problembased and inquiry-based learning. We would however argue that these particularities are exchangeable within the framework because the procedures in the five phases, as described, are independent target groups, subjects and pedagogical approaches. These procedures, which to a large extent stem from interaction design methodology, are frequently used in design for various target groups, subjects and pedagogical approaches.

This is our theoretical argument, but in order to reach a more certain conclusion regarding generalizability we recognize that the framework has to be empirically tested and applied by other researchers and designers in other areas and for other target groups.

Competing Interests

The authors declare that they have no competing interests.

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