Context-aware learning spaces (CALSs) are mobile-based learning environments which utilise contextual resources, such as real world objects, in the learning process. This dissertation presents the development of two technical platforms on which ten CALSs were created in 2007-2011. Based on the development experiences, a model and an evaluation tool for technology integration in CALSs are proposed. These results, both practical and theoretical, can be utilised by developers to create CALSs in which technologies have been integrated effectively so that they do not disturb the learner.
TEEMU H. LAINE

Technology Integration in Context-Aware Learning Spaces

Publications of the University of Eastern Finland
Dissertations in Forestry and Natural Sciences
No 59

Academic Dissertation
To be presented by permission of the Faculty of Science and Forestry for public examination in the Louhela Auditorium in Joensuu Science Park at the University of Eastern Finland, Joensuu, on December, 20, 2011, at 12 o’clock noon.

School of Computing
ABSTRACT

Context-aware learning spaces (CALSs) are mobile-based learning environments which utilise contextual resources, such as objects in the physical environment, in the learning process. The awareness of the surrounding context enables a CALS to take advantage of rich contextual resources in informal learning settings.

Technology integration refers to the process by which a technology is introduced to a classroom so that the teacher and the students can use it effectively for pedagogical purposes. While technology integration has been typically researched in the context of formal classroom-based education, it has not received similar attention in informal learning settings, particularly in the case of CALSs, even though a large part of learning occurs in informal contexts as part of everyday life.

Research and development work was conducted in Finland, South Korea, South Africa and Mozambique in 2007-2011. During those four years, two CALS platforms and ten CALSs based on the platforms were developed using an exploratory software development method. The platforms were based on the client-server architectural approach and utilised technologies such as mobile devices, sensors, smart tags and wireless networking. The created CALSs were games for various purposes and contexts including, but not limited to, mathematics in classrooms, environmental awareness in a forest, history in a technology museum, and science in a science festival. The analyses conducted on the games, together with literature analyses, informed the creation process of a technology integration model which describes the requirements and the critical factors that should be taken into account in the design phase of a CALS. Furthermore, based on the model and a literature analysis, a tool was created to facilitate the evaluation of technology integration in CALSs. An evaluation conducted with the tool indicated that it provides more accurate results with a smaller data set than an evaluation without the tool.

This research represents both practical and theoretical perspec-
tives, thus proposing an holistic approach to technology integration in CALSs. The outcomes fulfill the overall objective which was to provide the developers with the tools for construction and evaluation of CALSs in which technologies have been integrated effectively so that they do not disturb the learner.

Universal Decimal Classification: 004.9, 37.041, 37.091.33, 37.091.64

AMS Subject Classification: 68U35, 97D40

Library of Congress Subject Headings: Context-aware computing; Mobile computing; Non-formal education; Learning; Educational technology; Instructional systems; Educational games; Evaluation; Mathematics; Environmental education; History; Museums; Science – Study and teaching; Computer software – development; Software engineering

Keywords: context-awareness; informal learning; mobile-based learning; context-aware learning space; system architecture; technology integration; technology integration evaluation
Preface

I am deeply grateful to my supervisors Professor Erkki Sutinen and Associate Professor Mike Joy who ensured that this research did not sidetrack too much. They shared their wisdom over numerous conversations which helped me not only to become a proficient author but also a critical thinker. While long talks with Erkki inspired me to release my creativity in ways which I thought were not possible, discussions with Mike helped me to scrutinise and rationalise my research so that it made sense.

I owe my appreciation to Professor Mike Sharples and Associate Professor Hiroaki Ogata for performing amazing work while pre-examining this dissertation, which now meets the high standards of academic quality. I would also like to express my gratitude to the defense opponent Professor Alfredo Terzoli for challenging me so as to ensure the appropriateness of this research.

Carolina Islas Sedano and Mikko Vinni are the two most important colleagues with whom I was honoured to work during the past five years. Without this effective collaboration I probably would have never ended up doing a PhD. It was Carolina who had a magnificent idea of creating a pervasive game for the SciFest 2007. She invited Mikko and me to join the team, and the rest is history. Together we have gone through ups and downs of academic work, lending a hand to each other in developing games, evaluating, paper authoring and overcoming researcher’s blocks.

The year that I spent in South Korea (2007-2008) would not have been possible without the great hospitality of Professor Chaewoo Lee from Ajou University who invited me to work in his Multimedia Networking Laboratory (MNLab). I am grateful to the students of the MNLab who taught me the true meaning of hard work and dedication to research. Specifically, I am thankful to Jinchul Choi and Kitak Yong who contributed to the creation of the Heroes of Koskenniska
game.

Other individuals to whom I am grateful for assisting in this research are: Eeva Nygren (née Turtiainen) for inventing the UFractions game and evaluating it together with me in Africa and in Finland; Anna Gimbitskaya and Ewa Kowalik for contributing to the Heroes of Koskenniska game; Professor Seugnet Blignaut and Andrew Smith for collaborating in research related to UFractions; Leenu Juurela, Riina Linna and Marianna Karttunen from the Museum of Technology in Helsinki for participating in the creation of TekMyst, TekGame and TekGuide; Liisa Eskelinen and Marketta Haavila from the Pielinen Museum for participating in the creation of LieksaMyst; and any other individuals whom I have forgotten to mention but who would deserve to be mentioned here for contributing to this research in any way. I sincerely thank you all!

The School of Computing at the University of Eastern Finland (previously: the Department of Computer Science at the University of Joensuu) supported this research by granting research and travel scholarships as well as by providing research facilities and services. The East Finland Graduate School in Computer Science and Engineering (ECSE) granted me a scholarship during which a large part of the results of this research emerged. I am grateful to University of Eastern Finland for granting me several opportunities to conduct research abroad – these experiences will be extremely valuable in the future.

I am thankful to our kind and knowledgeable secretaries Eeva Saukkonen and Tarja Karhu who accepted endless requests of information with smiles. Without their hard work and professionalism I would still be navigating through the red tape.

The very foundations of my education can be attributed to my parents Kaisu and Pertti who raised me with love and care. They never doubted my choice of career and always encouraged me to become the first doctor in the extended family. So here I am, extremely grateful for all your support and hopefully making you proud!

My wife Monika deserves the most of my gratitude. Without her unconditional love, support and encouragement I would have never
reached this point. Since 2002, she has witnessed my long ascent from a computer support guy to a university student and then to a PhD candidate. I have been very lucky to have her to stand by my side while conducting research in amazing places around Asia and Africa. She never questioned my progress even during the times when my research was nearly in standstill. Whenever I needed to go beyond the ordinary working hours (do such exist for a PhD candidate!?), Monika was very understanding and supported me in every possible way.

Finally, I dedicate this work to my late grandmother Laina Laine. I was inspired by her willpower and *sisu* which helped me to go through the hard times.

In Helsinki, November 30, 2011  
*Teemu H. Laine*
LIST OF PUBLICATIONS

This dissertation presents the outcomes of the author’s research on context-aware learning spaces in the field of educational technology. The following publications have been selected to be part of the dissertation:


These publications will be referred to by Roman numerals throughout the dissertation. Chapter 2 links the publications to research questions.
AUTHOR’S CONTRIBUTION

The publications selected to be part of this dissertation are original research papers on context-aware learning spaces (CALSs) and technology integration in them. The author was the primary contributor to the ideas and the manuscripts. The ideas for papers IV-VII emerged through discussions with Professor Sutinen. The CALSs which are described or referred to in papers II-V have been created in collaboration with Carolina Islas Sedano and Mikko Vinni who have also provided comments for those papers and co-created all evaluation designs for these CALSs. Islas Sedano’s role has been the game and user interface designer while Vinni and the author have created the technical foundations for the CALSs. Specifically, Vinni and the author have created the Myst platform. The author created the first version of the HoK platform in 2009 with a group of computer science students and Vinni joined the author to develop the platform further in 2010. The idea and the designs for the UFractions game presented and evaluated in papers VI-VII were originated by Eeva Nygren (née Turtiainen) and the author was responsible for the technical development of the game. Furthermore, Nygren and the author jointly designed and conducted evaluations for papers VI-VII. Dr Joy and Professor Sutinen contributed to papers in which they appear as co-authors by commenting paper drafts and giving ideas for improvements.
LIST OF TERMS AND ABBREVIATIONS

2D bar code  Two dimensional bar code – an optical smart tag solution

Affordance  An enabling feature of an object or an environment that allows an individual to perform an action

Android  A mobile platform developed by Google

Backend  Part of a software that is hidden from the user and typically contains the business logic

CALS  Context-Aware Learning Space

Client-server architecture  An approach to system architecture where multiple clients connect to a centralised server component

Constraint  A limiting force that sets restrictions to the use of technology in pedagogy

Context  A collection of interrelated contextual entities

Context-awareness  Ability of a system to recognise and act upon changes in consecutive situations (i.e. temporal snapshots) in a context

Context-aware learning  A form of learning which utilises the resources of the surrounding context

Context-free resource  Resource that is not dependent on a given context

Context-sensitiveness  Ability of a system to adapt to the user’s situation

Contextual entity  A property which can be used to describe a certain aspect of a context, e.g. time, weather, user’s location or an object residing within the context
Contextual resource  A contextual entity that can be observed by
a given set of context-aware technologies

Data source  A system component that provides data to the system,
e.g. a sensor

Disturbance factor  An element in a CALS that has a negative
effect on the learners

Frontend  User interface of a system

GPS  Global Positioning System

iOS  A mobile platform developed by Apple

J2ME  Java 2 Mobile Edition – a Java platform for mobile phones

Java  A programming language originally developed by Sun Microsys-
tems

Learning space  A combination of physical and virtual realities in
which the learning takes place

MeeGo  A mobile platform originally developed by Nokia and Intel

Middleware  A software component that mediates data communi-
cation between data sources and a server backend

Mobile learning  A form of learning in which the learners have time
and location independent access to learning resources via a mo-
bile device

Model-View-Controller  A software architecture pattern where soft-
ware comprises a model (data), a view (representation of the
data) and a controller (methods to interact with the software)

MUPE  Multi-User Publishing Environment – a mobile publishing
platform developed by Nokia

NFC  Near Field Communication – a smart tag solution based on
RFID
Pervasive learning  A special case of context-aware learning where
the learning is connected to a specific context

PLS  Pervasive Learning Space

RFID  Radio Frequency IDentification – a short-range wireless com-
munication technology comprising RFID reader devices capable
of reading RFID tags

Sensor  A hardware component that is capable of detecting changes
in a contextual entity

Situation [in a context]  A snapshot of a context at a given mo-
ment of time

Smart tag  A tagging technology that can be used to make objects
detectable by a context-aware system

Technological Pedagogical Content Knowledge (TPCK)  A tech-
nology integration framework suggesting that a competent teacher
should master knowledge of technology, pedagogy and content
matter

Technology integration  A process by which a technology is intro-
duced to a pedagogical setting

Ubiquitous learning  A special case of context-aware learning where
the learning spans across contexts

ULS  Ubiquitous Learning Space

XML  eXtensible Markup Language
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Research objectives and outcomes</td>
<td>7</td>
</tr>
<tr>
<td>2.2</td>
<td>CALSs and platforms created during this research</td>
<td>9</td>
</tr>
<tr>
<td>3.1</td>
<td>Examples of changes in the contextual entities between two consecutive situations</td>
<td>17</td>
</tr>
<tr>
<td>3.2</td>
<td>Detection of changes between situations in a context-aware system</td>
<td>19</td>
</tr>
<tr>
<td>3.3</td>
<td>Comparison of two context-aware system frameworks</td>
<td>20</td>
</tr>
<tr>
<td>3.4</td>
<td>Types of learning</td>
<td>22</td>
</tr>
<tr>
<td>3.5</td>
<td>Tool Integration Process model</td>
<td>26</td>
</tr>
<tr>
<td>4.1</td>
<td>Working principle of MUPE</td>
<td>30</td>
</tr>
<tr>
<td>4.2</td>
<td>The Myst platform architecture</td>
<td>32</td>
</tr>
<tr>
<td>4.3</td>
<td>SciMyst player recording a 2D bar code</td>
<td>34</td>
</tr>
<tr>
<td>4.4</td>
<td>Excerpts from the story of Jussi the forest worker</td>
<td>36</td>
</tr>
<tr>
<td>4.5</td>
<td>An example of a mathematical challenge in UFractons</td>
<td>37</td>
</tr>
<tr>
<td>4.6</td>
<td>The HoK platform architecture</td>
<td>39</td>
</tr>
<tr>
<td>4.7</td>
<td>Two players solving a challenge in Heroes of Koskenniska</td>
<td>40</td>
</tr>
<tr>
<td>5.1</td>
<td>Technology integration (TI) process in a CALS</td>
<td>44</td>
</tr>
<tr>
<td>5.2</td>
<td>Technology integration model for CALSs</td>
<td>45</td>
</tr>
<tr>
<td>5.3</td>
<td>Passive and active integration of technology in CALSs</td>
<td>47</td>
</tr>
</tbody>
</table>
LIST OF TABLES

2.1 Connections between research questions, papers and research methods ........................................... 6

3.1 Categories of context-aware technologies ................... 18
3.2 Examples of context-aware learning spaces ................. 23

4.1 CALSs based on the Myst platform ........................ 31

A.1 Characteristics of CALSs ..................................... 73

B.1 Learner’s role in the evaluation tool ....................... 75
B.2 Educator’s role in the evaluation tool ..................... 76
B.3 Context’s role in the evaluation tool ....................... 77

C.1 Disturbance factors found in the first evaluation of UFractions .................................................. 80
C.2 Disturbance factors found in the second evaluation of UFractions ............................................. 81
Contents

1 INTRODUCTION 1

2 RESEARCH QUESTIONS AND DESIGN 5
  2.1 Q1: What features characterise context-aware learning spaces (CALSs) within the domain of mobile-based learning tools? 6
  2.2 Q2: How can a CALS platform be constructed? 8
  2.3 Q3: How can technology integration be taken into account in the design phase of CALSs? 10
  2.4 Q4: How can technology integration in CALSs be evaluated? 12

3 BACKGROUND 15
  3.1 Informal learning 15
  3.2 Context-awareness 16
  3.3 Context-aware learning spaces (CALSs) 21
  3.4 Technology integration in education 24
  3.5 Summary 27

4 PLATFORMS FOR CALS 29
  4.1 The Myst platform 29
    4.1.1 SciMyst 2007-2009 33
    4.1.2 ADEMyst 33
    4.1.3 TekMyst 34
    4.1.4 EdTechMyst 35
    4.1.5 LieksaMyst 35
    4.1.6 UFractions 36
  4.2 The HoK platform 38
    4.2.1 Heroes of Koskenniska 39
    4.2.2 TekGuide and TekGame 40
  4.3 Characteristics of a reusable CALS platform 42
1 Introduction

Context-aware learning spaces (CALSs) are mobile-based learning environments, typically deployed to informal pedagogical settings, which utilise surrounding contextual elements (e.g. museum exhibits) in the learning process. The term learning space refers to a combination of physical and virtual realities in which the learning takes place. A typical CALS comprises a number of mobile devices (clients), wireless connectivity, a server, a set of context-aware technologies and a collection of context-sensitive learning content and activities. By being aware of the context, CALSs are able to connect the learning content to the surrounding context so as to motivate the learner to explore the physical environment in a way that has not been possible in traditional mobile learning [21].

This dissertation lays the foundations for CALS development from four perspectives. First, the CALS concept is defined and its characteristics are described so as to position this research in the domain of mobile-based learning tools. Secondly, the process of creating the technical infrastructure for a CALS is reviewed through the development history of two CALS platforms on which ten game-based CALSs were constructed. These CALSs were created for various purposes in diverse contexts including, but not limited to, raising environmental awareness in a Finnish forest (paper IV), taking a visitor back in time to meet people from the past in an open air museum [40], providing a science festival visitor an alternative way of exploring exhibitions and workshops [38] and teaching mathematics to South African children with a story-based game [87]. Thirdly, the role of technology integration in the design process of a CALS is analysed and a model for technology integration is proposed to assist the CALSs developers to deploy appropriate technologies to meet various requirements of a CALS. Fourthly, a technology integration evaluation tool is proposed to support iterative improvement of CALSs.

CALSs have a degree of context-awareness through which they can detect changes in the surrounding context and act upon those
changes. This means that a CALS delivers content to the learner based on the learner’s context, for example where they are, what time it is, what they are doing, who else are with them, how are they feeling and what is the state of the surrounding environment. The CALS uses context-aware technologies such as sensor devices [59], smart tags [2] and positioning [37] to detect these versatile contextual resources. Utilisation of the contextual resources to facilitate learning processes in a CALS depends on pedagogical and design objectives as well as availability of resources (e.g. time, money, know-how). In an optimal case a CALS provides highly personalised and contextually relevant learning content to the learners based on the situations in which they are embedded. For example, changes in the environmental parameters such as temperature, humidity and illumination between different physical locations in a forest can be used to inform the learner of the features of different microclimates in these locations [50].

During four years of research and development, two CALS platforms and ten CALSs based on the platforms were developed. The incremental nature of the development was based on the ideas and the solutions of the previous stages. Various technologies were utilised in the process including, but not limited to, mobile devices, wireless networks, sensor devices and smart tags. The method of acquiring context-awareness was mostly based on detecting the learner’s position and the presence of physical objects within the context. In one case an environmental sensor network was implemented so as to acquire deeper information on the context (paper IV). Due to the presence of technology in CALSs, an investigation into the concept of technology integration was deemed to be necessary.

Technology integration refers to the process by which a technology is introduced into a classroom so that the teacher and the students can use it effectively for pedagogical purposes [20]. Poor technology integration may lead to disruptions in teaching and learning or to wasted technology resources. While technology integration has been typically researched in the context of formal classroom-based education, it is clear that the same challenge is present in informal learning.
Introduction

contexts as well. This is particularly true in the case of CALSs due to the technology’s central role in them. For example, disregarding the influence of the technology on the learner and on the context in a museum-based CALS could result in poor learning experiences and even annoyance. Because the concept of a CALS is novel, there has not yet been research aimed at establishing the foundations of technology integration in CALSs.

This dissertation summarises the results of seven original research papers (I-VII) under seven chapters as follows. First the research questions and design are described, including the methods which were applied to answer the questions. Then follows the background in Chapter 3 where the research is positioned in the field of mobile-based learning and central concepts are defined. In Chapter 4, overviews are presented of the two CALS platforms and the ten CALSs created on the platforms. Technology integration in CALSs is covered in Chapter 5. Specifically, the technology integration model is introduced in Section 5.1 and a tool for evaluating technology integration in CALSs is described in Section 5.2. Finally, the implications of the results are described and analysed in Chapter 6 before concluding the work in Chapter 7 with suggestions for future research activities.
2 Research questions and design

There are four objectives for this dissertation: (i) to position the concept of a CALS within the field of mobile-based learning tools; (ii) to design and implement a reusable platform for CALSs; (iii) to explore the role of technology integration in CALS development and to find a model to facilitate it; and (iv) to evaluate technology integration in CALSs. While these goals represent both practical and theoretical perspectives of CALS development, they share the same overall objective: to provide the developers with the tools for construction and evaluation of CALSs in which technologies have been integrated effectively so that they do not disturb the learner.

The four goals are answered by four research questions which use various methods. The research questions are summarised in Table 2.1 together with references to the relevant papers, research methods and chapters in which the questions are answered. More detailed descriptions of each research question, its purpose and its methods are presented in the following sections.

The research work presented in this dissertation was conducted between 2007 and 2011 in Finland, South Korea, South Africa and Mozambique. It was an exploratory journey during which ten game-based CALSs, two CALS platforms, a technology integration model and a technology integration evaluation tool were created. Each game, except the first one, built on the foundations and experiences of the previous games. The platform development paths followed closely the development sequences of the games. New game designs uncovered new requirements that had to be dealt with by platform development activities. Through the experiences acquired by the research and development activities, a thought emerged that it would be beneficial to know how to integrate various technologies with CALSs in an effective manner so that the end result would provide good learning experiences. Then started the theoretical work towards a technology integration model which was further extended with an evaluation
Table 2.1: Connections between research questions, papers and research methods

<table>
<thead>
<tr>
<th>Research question</th>
<th>Papers</th>
<th>Methods</th>
<th>Ch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 What features characterise context-aware learning spaces (CALSs) within the domain of mobile-based learning tools?</td>
<td>I, II</td>
<td>Literature analysis</td>
<td>3</td>
</tr>
<tr>
<td>Q2 How can a CALS platform be constructed?</td>
<td>III, IV</td>
<td>Exploratory software development, mixed method evaluation</td>
<td>4</td>
</tr>
<tr>
<td>Q3 How can technology integration be taken into account in the design phase of CALSs?</td>
<td>II, V, VI</td>
<td>Literature analysis, artefact analysis</td>
<td>5</td>
</tr>
<tr>
<td>Q4 How can technology integration in CALSs be evaluated?</td>
<td>VII</td>
<td>Literature analysis, mixed method evaluation</td>
<td>5</td>
</tr>
</tbody>
</table>

An illustration of the objectives and outcomes of this research as well as relations between the components is presented in Figure 2.1.

All evaluations performed in this research were carefully designed and necessary precautions were taken to ensure the anonymity of the participants. The participants or their guardians also signed research consent forms before partaking in any activities which involved research data collection.

2.1 Q1: WHAT FEATURES CHARACTERISE CONTEXT-AWARE LEARNING SPACES (CALSs) WITHIN THE DOMAIN OF MOBILE-BASED LEARNING TOOLS?

By answering this research question I aim at defining the concept of a context-aware learning space and position it in the domain of mobile-based learning tools. This is necessary so as to give the reader a perspective on the topic of the dissertation. Chapter 3 answers this research question.
The research method for answering Q1 is literature analysis. Literature was acquired by systematically querying popular scientific search engines such as Google Scholar, ACM Digital Library and IEEE Xplore, and then following relevant references of the discovered articles. Additionally, the following conferences and workshops were used as data sources for paper I:

In paper I the literature analysis focused on state-of-the-art systems, the technologies used, the roles of mobile devices and the applied learning models. In paper II the focus was on pedagogical approaches for informal learning settings, including situated learning, authentic learning, contextual learning, group-based learning, exploratory learning, problem-based learning and museum learning. Finally, part of the literature analysis of paper II establishes a division between various mobile-based learning approaches which form the basis for the concept of a CALS.

2.2 Q2: HOW CAN A CALS PLATFORM BE CONSTRUCTED?

The aim of this research question is to identify the properties of a reusable CALS platform and to describe the process of building it. Results are useful for researchers who wish to establish their own reusable CALS platforms. Chapter 4 answers this research question.

Two platforms and ten game-based CALSs were developed during this research. From the perspective of software development, the Exploratory Software Development (ESD) [86] method with an iterative structure was used in the development. Trenouth [86] suggests that
the ESD method is suitable in situations where a client is unclear about the requirements or if a specification is unavailable because the domain of application is poorly understood. In the case of this research it was the latter that required the use of an exploratory method of software development. The process was iterative in that the development of the CALSs were based on previous CALSs, except for SciMyst 2007 which was the first one. When a new CALS was created, the platform was adapted to the new requirements while retaining the flexibility. At some point the requirements set by a CALS concept required creation of a completely new platform, hence this research proposes two platforms. The overall evolution of the platforms and the CALSs is presented in Figure 2.2.

![Diagram](image)

*Figure 2.2: CALSs and platforms created during this research*

From the game design perspective all CALSs except UFractions were created by using the Hypercontextualised Game (HCG) design approach [40]. In the HCG, the game is deeply rooted in the same context in which the player is embedded. The process emphasises
creativity, innovation, self-expression and the knowledge of the stakeholders who are involved in the design process from the beginning. The design work is based on workshops which are orchestrated by an HCG expert with an aim to identify and utilise meaningful resources from the context in the game play.

UFractions was designed by using the principles of the contextual design method [64] whereby the designer aggregates data from the target context and then designs a product based on the data. The designer of UFractions (Eeva Nygren) spent three months in South Africa to collect materials and to design the concepts and the contents for UFractions together with local experts on pedagogy and culture.

A mixed method approach [10] combining quantitative and qualitative strategies was used to evaluate all CALSs except ADEMyst and EdTechMyst, but not all evaluations have been published. The evaluations aimed at gathering learners’ background information, opinions, motivation, suggestions for improvements and a varying number of other parameters. Data collection methods were primarily pre-test and post-test questionnaires supplemented in some cases with qualitative interviews and observations. Questionnaires had both quantitative multiple choice statements and qualitative open questions. Approaches for data analysis were study-specific, but typically average and standard deviation calculations were applied to quantitative data while supporting evidence was extracted from qualitative data.

2.3 Q3: HOW CAN TECHNOLOGY INTEGRATION BE TAKEN INTO ACCOUNT IN THE DESIGN PHASE OF CALSs?

Through this research question I aim at establishing a model of technology integration which facilitates the CALS development process. The model can be used by CALS developers to plan technology integration so that the outcome will not hinder or distract from the learning process. This research question is answered in Chapter 5 under Section 5.1.

To answer the third research question, two methods were applied:
literature analysis and artefact analysis. The theoretical foundations of the technology integration model were based on two literature analyses which are described in Section 2.1. Additionally, several smaller scale literature analyses were conducted which investigated for example the aspects of learning in museums, CALSs for specific themes such as environmental education, the use of wireless sensor technologies, and the requirements of technology integration in educational settings. These secondary, but equally important, pieces of information also contributed to the creation process of the technology integration model.

Artefact analysis is a research method which has been typically used in fields such as archaeology, history and arts to research on human-made objects. The goal of an artefact analysis is to reach a deeper understanding about an artefact and its usage than what would be possible by mere direct observation. The artefacts (i.e. CALSs) were analysed from two perspectives [69]:

1. artefacts as designed – looking at the ways in which the explicit and implicit knowledge of the designer are exposed in artefacts

2. artefacts as used – looking at the way on which people have appropriated, annotated and located artefacts in their work environment

The as designed artefact analysis was used on developed CALSs in order to determine the key requirements which were met by the use of technology during the development processes. Specifically, the decisions regarding inclusions or exclusions of technologies and the methods of implementing them were scrutinised. In the as used artefact analysis, usability, users’ perceptions and experiences were evaluated for several CALSs. A mixed-method approach was used in this evaluation as explained in Section 2.2. The aim was to see how the design decisions, i.e. designers’ ideas on how technology would be integrated, were reflected in the real use scenarios. As an example, in the case of the LieksaMyst game (Section 4.1.5), the as designed analysis revealed that simple wooden tags were used instead
of state-of-the-art object tagging technology because the context’s culture sought to preserve authenticity (paper V). From the users’ perspective the wooden tags worked without problems but there were some other usability issues which indicated problems with technology integration.

2.4 Q4: HOW CAN TECHNOLOGY INTEGRATION IN CALSs BE EVALUATED?

To answer this research question a tool was created for evaluating technology integration. The tool is based on the technology integration model (paper V, Q3) and it can be used by CALS developers and stakeholders to evaluate how well the technology has been integrated into a CALS. Chapter 5 answers this research question.

Before establishing the evaluation tool, the need for technology integration was determined by evaluating the UFrations game with a data set that was originally meant for measuring the effect of reverse transfer of a learning technology from a technology-alien context (South Africa) to a technology-familiar context (Finland) [51]. A mixed-method approach was used for the evaluation as described in Section 2.2. Additionally, a qualitative data categorisation and analysis method was used, which was also used in the evaluation tool and is described in detail below. The results of the evaluation indicated the need for technology integration (see Section 5.1) but since the data set was not designed for evaluating technology integration, the work began towards creation of the evaluation tool.

A literature analysis and the foundations of the technology integration model were used in the derivation of the evaluation tool for technology integration. Literature on technology integration in education was acquired and analysed, and the results combined with the technology integration model. Data were primarily collected by searching for articles related to technology integration in formal pedagogical settings. These findings were later complemented by analysing articles on technology appropriation and acceptance in the context of mobile learning.
Once the evaluation tool was constructed, it was used to evaluate UFractions, one of the CALSs developed during this research. The aim of the evaluation was not only to evaluate technology integration in UFractions but also to evaluate the feasibility of the technology integration evaluation tool. The evaluation utilised a mixed-method approach combining both qualitative and quantitative strategies. A descriptive analysis of the quantitative data was performed with mean and standard deviation calculations as well as Pearson correlation metrics. The findings were then supported by qualitative data. A mixed-method approach was chosen to get not only meaningful statistical results but also deeper complementary insights on the participants’ views on the technology integration. Specifically, qualitative data were used to support and explain the quantitative conclusions that were drawn from the statistical analysis of the data set. Furthermore, qualitative data categorisation and analysis were the key methods for identifying disturbance factors which affect negatively the users of UFractions. First, a set of indicators were established and based on them the factors from the open questions and interviews were identified. The categorisation was coded according to the types of negative responses that the participants gave in open questions and interviews. The data collection techniques used in the evaluation included interviews, questionnaires, recording of application usage statistics, and observations. Interviews were based on a set of prepared questions with an option to apply clarifying questions. Questionnaires had both closed and open-ended questions, and observation remarks were done by hand by a researcher during the experiments.
3 Background

3.1 INFORMAL LEARNING

Informal learning occurs outside formal learning settings and it complements formal educational systems. It has been estimated that a good majority of learning takes place in informal contexts [54,85]. In the past, before the establishment of the institution of formal education, informal learning was the prevalent way of education. People would learn and share knowledge by visiting a neighbouring village to exchange news or developing a new handicraft skill as an apprentice guided by a master. This learning from experience is a key characteristic of the informal end of the continuum of formality in learning [17]. Other characteristics include, but are not limited to, implicit, unintended, opportunistic and unstructured ways of learning and the absence of a teacher [19], as well as contextual (organisational) embeddedness, action orientation, non-routine conditions, tacit dimensions, and a requirement for critical reflectivity and creativity [89].

In informal learning, the context in which the learning takes place is not solely dedicated to the purpose of learning, but learning just happens to take place there as a secondary function. This aspect is different from formal classroom-based education where the primary function of the context is to foster learning and teaching. The richness of and the interest raised by the surrounding context may increase the intrinsic motivation of the learner [13], which in turn may lead to flow, a state of mind in which the learner is completely immersed in the learning process [14]. The involvement of the context also works as a catalyst for educators to implement alternative learning activities which are connected to objects and phenomena within the context.
3.2 CONTEXT-AWARENESS

In this research, context is understood as a collection of interrelated contextual entities. A situation is defined as a snapshot of a context at a given moment of time. Contextual entities may be identified, for example, by knowing where the users are, what they are doing, how they are feeling, who else is with them, what resources are nearby, what time it is and what the parameters of the physical environment are. Examples of contextual entities include the current time, the current weather, and the physical location of the user (e.g. geographical coordinates). Zimmermann et al. define a contextual entity as an element which can be described by using categories of individuality, activity, location, time and relations [93]. From this follows that Zimmerman et al.’s contextual entity can be observed from many different observation points whereas in my definition a contextual entity corresponds to a single observation point.

This research concentrates on real world contexts, i.e. contexts which are situated in physical spaces. A context can be divided further into subcontexts. For example, a museum context comprises the physical context (museum building, rooms, objects), the sociocultural context (of staff, visitors), the temporal context (time of the day/week/month/year), the political context (museum policies), the pedagogical context (learning material and objectives), and the personal contexts (previous experiences, skills, preferences) of the visitors. Figure 3.1 illustrates how some of the contextual entities of the Heroes of Koskenniska game (see Section 4.2.1) change between two situations which are separated by time. These contextual entities are not comprehensive – others could be for example user’s rate and direction of movement, user’s posture, user’s spatial relationship to nearby users, relevant people available online, and so forth.

From the definition of context follows context-awareness, which is defined as a property of a system to recognise and act upon changes in consecutive situations (i.e. temporal snapshots) in a context. In order for a system to be context-aware it needs to utilise context-aware technologies. Based on my understanding of the field, technologies
used in context-aware systems can be roughly categorised into front ends, wireless networking, input technologies, output technologies, smart tags, sensor devices, middleware and back ends. Table 3.1 presents these categories together with explanations and examples. With regard to the example in Figure 3.1, various sensors could be used to detect the status of the environment as well as of the users. The current version of Heroes of Koskenniska utilises temperature, illumination and humidity sensors. The user’s location is detected by solving riddles at specific locations (Magic Spots).

Figure 3.2 illustrates how a context-aware system detects changes between two consecutive situations in a context. Specifically, the system detects changes ($\Delta_1$ and $\Delta_2$) in contextual resources ($\text{Entity}_1$ and $\text{Entity}_2$) which form a subset of contextual entities that can be observed by a given set of context-aware technologies and then utilised by the system. In contrast, $\text{Entity}_3$ is not a contextual resource because it is not detectable by the context-aware technologies. Context-free resources are not dependent on a given context (e.g. a
Table 3.1: Categories of context-aware technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Explanation</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front end (mobile device)</td>
<td>Connects user to the back end and to other users</td>
<td>Use mobile device to send and receive data to/from the context-aware system</td>
</tr>
<tr>
<td>Wireless networking</td>
<td>Relays data between wireless entities</td>
<td>Collect data from a wireless sensor network and relay them to the middleware</td>
</tr>
<tr>
<td>Input devices</td>
<td>Receive data and commands from the user</td>
<td>Use movement-based sensors (e.g. Microsoft Kinect) to allow natural interaction with the system</td>
</tr>
<tr>
<td>Output devices</td>
<td>Present content to the user</td>
<td>Use an augmented reality software module to view 3D objects through the mobile device’s camera viewfinder</td>
</tr>
<tr>
<td>Smart tags</td>
<td>Link physical objects or places to the context-aware system</td>
<td>Attach two dimensional bar codes or RFID tags to museum objects in order to make them detectable</td>
</tr>
<tr>
<td>Sensor devices</td>
<td>Detect parameters of various contexts (e.g. physical, personal)</td>
<td>Adapt learning activities according to learner’s location (GPS) and stress level (skin conductance sensor)</td>
</tr>
<tr>
<td>Middleware</td>
<td>Relay contextual data between the data providers (sensors, input devices, smart tags) and the back end</td>
<td>Wireless sensor network sends collected readings to the middleware which sends it to the back end and monitors data integrity at the same time</td>
</tr>
<tr>
<td>Back end</td>
<td>Contains business logic of the context-aware system</td>
<td>A context-aware game engine which presents challenges to the user based on context information acquired through middleware</td>
</tr>
</tbody>
</table>
Background

theory or general knowledge of a topic). By being aware of the contextual resources and changes in them, a system can adapt both the contextual and context-free resources to fit the user’s current situation. As a result, the system provides the user with context-sensitive materials and activities with high relevance to the user’s situation. In the case of Heroes of Koskenniska, contextual resources form a subset of all possible contextual entities. These contextual resources include timestamps, the user’s location (coarse and fine), temperature, humidity, illumination, nearby users and previously visited spots.

![Figure 3.2: Detection of changes between situations in a context-aware system which produces context-sensitive materials as output](image)

The amount of context-awareness required is specific to the application – in some cases knowing the user’s location within a geographical area is enough [4] whereas in other applications it may be necessary to detect the parameters of the surrounding environment [50,59]. Sometimes it may even be necessary to detect changes in the user’s body [3]. As creating a highly context-aware system requires money and time, trade-offs are necessary in the design process. Furthermore, state-of-the-art technology can also become a burden if it is not integrated properly, resulting in a situation where the technology is disrupting the user experience [44] or the system simply does not work because of a lack of technical maintenance skills.

There are other works which discuss context-aware systems and the role of context in them (e.g. [5,18,55]). My definition of a context-
aware system in Figure 3.2 relates closely to Lonsdale et al.’s framework which is based on content recommendations [55]. In this framework a context subsystem uses metadata from the context, including the user, and the content to provide recommendations as to what type of content would be appropriate for the users in their current situations. The context is defined hierarchically so that the overall context comprises context states, context substates and context features. Figure 3.3 compares the Lonsdale et al.’s context-aware system framework to mine (see Figure 3.2). The main difference between the two frameworks is that my framework also accounts for such contextual entities that are not currently detectable by the system (i.e. Contextual Entity 3 in Figure 3.3) but could be included in a later stage of development. Context Substate does not correspond to a set of Contextual Entities because the former leaves out some of the potential Context Features.

Figure 3.3: Comparison of two context-aware system frameworks: Lonsdale et al. [55] (left) and mine (right)
3.3 CONTEXT-AWARE LEARNING SPACES (CALSs)

Context-aware learning is a fairly new concept in the domain of educational technology and it utilises resources of the surrounding context. Context-aware learning typically takes place in informal learning settings where the context is rich in terms of learning possibilities. It builds on the foundations of mobile learning (m-learning) in which the learners with mobile devices have time and location independent access to learning resources (see e.g. [21, 62, 77]). A major challenge in m-learning is that the richness of the surrounding context is not considered. This means that the same learning material can be studied at home, at school, in a bus or in a park, thus the surrounding context is disregarded and the learner’s attention can be too much focused on the mobile device’s screen [23]. As a remedy for ignoring the contextual relevance in m-learning, context-aware learning (also built on portable handsets) integrates the surrounding contextual resources into the virtual learning content. A mobile handset delivers context-sensitive instructions and learning tasks to the learner and provides relevant feedback upon the learner’s actions. Because of the context-sensitiveness of the learning content, the learner is encouraged to make observations of and to interact with surrounding objects and phenomena. Context-sensitiveness is achieved by context-aware technologies as described in Section 3.2.

A learning environment which makes use of a context-aware system is referred to as context-aware learning space (CALS). The term “learning space” in this case refers to a combination of physical and virtual realities in which the learning takes place. A typical CALS comprises a number of mobile devices (clients), wireless connectivity, a server, a set of context-aware technologies and a collection of context-sensitive learning content and activities. CALSs can be further divided into pervasive learning spaces (PLSs) and ubiquitous learning spaces (ULSs). Although the terms “pervasive learning” and “ubiquitous learning” are sometimes used as synonyms, this research distinguishes the two at the level of the learner’s mobility in respect to the context. A PLS is built for a specific context (e.g. a mu-
seum) whereas a ULS spans across several contexts (e.g. multiple locations in a city). Figure 3.4 illustrates the differences between pervasive learning, ubiquitous learning, mobile learning and desktop computer based learning in the domains of learner’s mobility and context-awareness. This division was adapted from the idea of Lyytinen and Yoo [57] and it has also been elaborated by Ogata and Yano [66].

Many research projects have been initiated to build learning environments which are context-aware at various levels. A selection of these CALSs are presented in Table 3.2 which also indicates whether the systems are ULSs or PLSs, i.e. do they span across different contexts or not. Information on context-awareness in the systems is also provided. Context-awareness is most commonly achieved by establishing position of the users but these examples show that also more advances technologies have been used, such as sensors.

Figure 3.4: Types of learning according to context-awareness and learner mobility
### Table 3.2: Examples of context-aware learning spaces

<table>
<thead>
<tr>
<th>CALS</th>
<th>Purpose</th>
<th>PLS/ULS</th>
<th>Context-awareness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Wood [71]</td>
<td>Support contextualised scientific inquiry during school field trips in forests</td>
<td>PLS</td>
<td>Light and humidity sensors, GPS for user positioning</td>
</tr>
<tr>
<td>Augmented Knight’s Castle [32]</td>
<td>Facilitate children’s playing and learning by technologically augmented toys</td>
<td>ULS</td>
<td>RFID for object detection</td>
</tr>
<tr>
<td>GreenSweeper [36]</td>
<td>Increase awareness of green areas in an urban environment through a game similar to Mine Sweeper</td>
<td>ULS</td>
<td>Manually inserted used location, captured images for detecting greenness</td>
</tr>
<tr>
<td>Context-sensitive microlearning environment [6]</td>
<td>Learn second language vocabulary through interaction with everyday objects</td>
<td>PLS</td>
<td>Object/furniture usage sensors, water flow sensors, accelerometers, RFID</td>
</tr>
<tr>
<td>Cyberguide [1]</td>
<td>Provide a context-sensitive tour to the visitors of a research laboratory</td>
<td>PLS</td>
<td>Infrared positioning</td>
</tr>
<tr>
<td>Environmental Detectives [47]</td>
<td>Support learning of environmental science through a multiplayer real-world simulation game</td>
<td>ULS</td>
<td>GPS for user positioning</td>
</tr>
<tr>
<td>JAMIOLAS [34]</td>
<td>Learn Japanese mimicry and onomatopoeia through context-aware learning activities</td>
<td>ULS</td>
<td>Wearable and wireless sensors, RFID for user positioning</td>
</tr>
<tr>
<td>LORAMS [65]</td>
<td>Learn and share everyday tasks through context-aware videos</td>
<td>ULS</td>
<td>RFID for object detection</td>
</tr>
<tr>
<td>Nottingham Castle Museum gallery (MO-BILearn) [56]</td>
<td>Receive context-sensitive information on paintings in a gallery</td>
<td>PLS</td>
<td>Ultrasound tracking for user positioning</td>
</tr>
<tr>
<td>REXplorer [4]</td>
<td>Support touristic context-aware exploration of Regensburg city through a game</td>
<td>PLS</td>
<td>Camera-based motion detection, GPS for user positioning</td>
</tr>
<tr>
<td>Via Mineralia [31]</td>
<td>Explore a mineral collection through a treasure hunt game</td>
<td>PLS</td>
<td>RFID for object detection</td>
</tr>
</tbody>
</table>
To establish characteristics of a CALS, two literature analyses were conducted. In the first literature analysis (paper I) it was discovered that mobile devices can be used in a CALS for data collection, content representation, communication, navigation and notifications. The same analysis suggested that client-server architectures were prevalent in the systems. The popularity of the client-server approach can be explained by the fact that the processing power of mobile devices may be too limited for many use cases. Additionally, it makes content maintenance easier as well as enabling multiuser features. Finally, the first literature analysis indicated the lack of a pedagogical model for CALSs.

In the second literature analysis (paper II), inspired by the lack of a pedagogical model, a set of pedagogical characteristics for pervasive learning spaces was derived (PLSs, a subset of CALS). The literature focused on constructivist approaches to situated learning, authentic learning, contextual learning, group-based learning, exploratory learning, problem-based learning and museum learning. I combined appropriate characteristics of these approaches as none them alone was suited for a PLS. As a result, 15 characteristics were identified which were later extended to 18 (paper V). The characteristics, presented in Table A.1, are categorised into five groups: (i) user profiles and perspectives; (ii) interaction and collaboration; (iii) ownership; (iv) authenticity and relevance; and (v) support and assessment. These characteristics can be used to evaluate the potential of a PLS as a learning tool. The results can be applied also to ULSs and therefore to all CALSs because a ULS can be thought of as a collection of interrelated PLSs [51].

3.4 TECHNOLOGY INTEGRATION IN EDUCATION

The term technology integration refers to the process by which a technology (typically digital) is introduced into a classroom so that the teacher and the students can use it effectively for pedagogical purposes. Technology integration in formal education has been researched extensively [7, 20, 53, 60, 81, 82].
Koehler and Mishra [48] have introduced the TPCK (Technological Pedagogical Content Knowledge) framework for technology integration in formal education. The TPCK framework is based on Shulman’s PCK (Pedagogical Content Knowledge) model which suggests that a competent educator should master both knowledge of pedagogy and knowledge of content [79]. Koehler and Mishra complemented the PCK model by adding the component of technology to it so as to meet the requirements of the current trends in pedagogy where various educational technologies are being increasingly combined.

Koehler and Mishra are not the first authors attempting to attach a technology component to the PCK model of Shulman. Earlier related works such as Keating and Evans [45], Pierson [67] and Niess [63] also used the PCK model when addressing the challenge of technology integration in classrooms. This research uses Koehler and Mishra’s framework as a reference due to its comprehensive and clear representation. Furthermore, the distinction and analysis of different combinations of the core components can be attributed to them.

Koehler and Mishra utilise the concepts of affordances and constraints in the technology integration process [48]. Affordances are enabling features of an object or an environment that allow an individual to perform an action. Constraints are a limiting force which sets restrictions to the use of technology in regard to pedagogy. For example, teachers can use traditional chalkboards to present text and hand-drawn graphics (affordances) but they are not able to create multimedia animations with them (constraint). Together affordances and constraints define how a technology can and cannot be used for educational purposes in a given context. Although traditional instruments such as chalkboards, overhead projectors and posters can be considered as technologies for education, this research focuses more on digital technologies.

The aforementioned studies on technology integration concentrated on formal classroom settings. There are also research which

focus on technology appropriation and acceptance in the context of mobile learning. Waycott [90] proposes the Tool Integration Process (TIP) model for analysing how the possibilities and constraints of a new mobile tool can mediate or change activities that the tool was built to support. This way of adopting and shaping a technology for new purposes while it is being used is referred to as appropriation. The TIP model, as illustrated in Figure 3.5, uses the foundations of activity theory, thus integrating the concepts of actions, operations, contradictions and breakdowns into the flow of events. Being user- and task-centric, the TIP model does not take into account the effects of the tool on the surrounding pedagogical setting (e.g. instructor and other learners) or to the surrounding context. However, it is useful for exploring how the learners adapt new technologies for new purposes that the designers of the technology did not consider.

![Figure 3.5: Tool Integration Process (TIP) model for mobile learning (adapted from [90])](image)

Jones and Issroff [43] analysed the motivational issues of mobile learning from two perspectives: technological appropriation ([11,90]) and Järvelä et al.’s model of coping strategies [41]. Through case studies they conclude that Waycott’s TIP model [90] is useful for understanding the larger contextual aspects of the use of mobile technologies, whereas the model of coping strategies is more applicable to small incidences of learning.

As a third example of research on technology integration in mobile
learning, Huang et al. complement the Technology Acceptance Model (TAM) [16] with two factors that they identified to cause individual differences in mobile learning: perceived enjoyment and perceived mobility value [35]. Huang et al. show that these two factors can be used to predict user acceptance of mobile learning. This result may be useful for predicting the success of technology integration in mobile learning environment but may not be applicable to context-aware learning spaces which typically comprise a versatile set technologies in addition to a mobile device.

3.5 SUMMARY

This chapter summarised the central concepts of this dissertation and while doing answered the research question Q1: *What features characterise context-aware learning spaces (CALSs) within the domain of mobile-based learning tools?* Specifically, the chapter presented the interlinked concepts of informal learning, context-awareness, context-aware learning space and technology integration. A CALS is based on various context-aware technologies which, in turn, aid the CALS to connect the resources of the physical context to virtual learning content, thus transforming the physical context into a learning space. The ability of CALSs to utilise resources of the context (e.g. surrounding objects) in the learning process makes them particularly useful for informal learning activities in contexts such as museums, science centres, urban areas, national parks and fairs. In principle, CALSs can be applied to any context having rich learning contents so as to facilitate context-aware learning activities and therefore release the hidden pedagogical potential within the context.

The majority of technology integration research efforts have concentrated on formal classroom-based education. However, it is equally important, if not more so, to consider the role and the effects of technology integration in informal learning settings. The importance of proper technology integration is particularly high in CALSs where the technology plays a significant role in the learning process. Since the concept of a CALS is novel, technology integration research has
not yet been applied to it. This research is motivated because without a proper integration of technology a CALS may distract and annoy the learners instead of leading them to the flow [14].
4 Platforms for CALS

Four years of research and development activities culminated in the creation of two CALS platforms: the Myst platform and the HoK platform. Both platforms were created for game-based CALSs but they can be used for other types of learning activities as well. The following sections present these platforms together with short descriptions of the CALSs that were created on the platforms. Finally, this chapter ends with a description of the characteristics of a reusable CALS platform. The aim is to answer the research question Q2: How can a CALS platform be constructed?

4.1 THE MYST PLATFORM

Similar to many other CALSs (see Section 3.3), the Myst platform (not to be confused with the commercial Myst game series) is based on a client-server architecture through Nokia’s Multi-User Publishing Environment (MUPE) [83]. The working principle of MUPE is presented in Figure 4.1 in which the Java-based MUPE server pushes requested content to the J2ME-based MUPE client in XML (eXtensible Markup Language) format, and the client renders the XML to display the corresponding user interface screen on the mobile device. The MUPE client has a plugin development interface which can be used to extend the client’s functionalities. The current set of plugins include for example support for GPS, NFC (Near Field Communication) and 2D bar codes. MUPE was chosen as the basis for the Myst platform because of its portability and the ease of deployment and maintenance as most operations are performed on the server side.

The Myst platform offers various game-like features to be used in CALSs. The most central features are enigmas which are a collection of challenges that the learner must solve. Enigmas are sensitive to the context in which the learner is, thus the learner must pay attention to the surrounding context in order to solve them. Enigmas come in many flavours, ranging from text-based queries to take-a-picture
tasks in which the user must locate an object based on a description and read a smart tag attached to it with a mobile device (i.e. treasure hunt). In addition to CALSs based on query-driven activities, the Myst platform also supports CALSs with a story-based structure, thus all Myst-based CALSs can be divided into story-telling games and treasure hunt/adventure games.

Another feature provided by the Myst platform is evidence recording in which the player takes pictures of some details of the physical context and attaches comments on the pictures. These recordings, appended with meta information such as player’s nickname, location and time stamp, are stored on the server and can be presented on the game website. The website is a feature of the Myst platform which must be customised for each game instance. Dynamic content on the website can include basic information of the game, instructions, game results (points), and galleries of recordings and collaborative battle (in which all players’ points are accumulated and compared against those of a common enemy).

The Myst platform has been used in eight game-based CALSs in various contexts. Table 4.1 shows these CALSs with descriptions and basic elements (adapted from paper III which describes the Myst platform in detail). The three SciMyst games only differ by content, hence they are grouped under one entry in the table.

As shown in Figure 4.2, the high-level architecture of the Myst platform can be divided into four distinct interconnected parts: the server, the clients, the physical environment, and the off-site exten-
### Platforms for CALS

#### Table 4.1: CALSs based on the Myst platform

<table>
<thead>
<tr>
<th>Game</th>
<th>Purpose and location</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>SciMyst (3 games)</td>
<td>Scientific treasure hunt for exploration of the SciFest science festival in Joensuu, Finland</td>
<td>Multiple choice questions, find-an-object tasks, record impressions, collaborative battle, website</td>
</tr>
<tr>
<td>AdeMyst</td>
<td>Promotional treasure hunt for ADE Oy’s products and services in Helsinki, Finland</td>
<td>Multiple choice questions, find-an-object tasks, record impressions</td>
</tr>
<tr>
<td>TekMyst</td>
<td>Treasure hunt on simple machines for the Museum of Technology in Helsinki, Finland</td>
<td>Multiple choice questions, multiple skill levels, find-an-object tasks, record impressions, collaborative battle, website</td>
</tr>
<tr>
<td>LieksaMyst</td>
<td>Storytelling time-travel game for learning how people used to live in the past at the open air Pielinen Museum, Lieksa, Finland</td>
<td>Interaction with past characters through a story, multiple choice questions, find-an-object tasks, alternative story branches, guest book, website</td>
</tr>
<tr>
<td>EdTechMyst</td>
<td>Treasure hunt to demonstrate the Educational Technology research group at the University of Eastern Finland, Finland</td>
<td>Multiple choice questions, find-an-object tasks, record impressions, collaborative battle, web site</td>
</tr>
<tr>
<td>UFractions</td>
<td>Storytelling adventure game for learning fractions with two leopards who are interacting with the learner. Developed for South African context but also deployed in Finland and in Mozambique.</td>
<td>Interaction with leopards through a story, usage of fraction rods, multiple choice questions, open-ended questions, record evidence of fractions, collaborative battle, alternative story branches, guest book, website</td>
</tr>
</tbody>
</table>
These components are described in detail in paper III. Context-awareness in Myst-based CALSs is primarily established through objects tagged either with two dimensional bar codes or short alphanumeric codes. The use of NFC tags is also supported but none of the Myst-based games uses them due to lack of support in client devices at the time of creating the games. Through the smart tags the server is aware of the user’s presence next to the objects and can also establish a rough estimate of the immediate social contexts of the users.

*Figure 4.2: The Myst platform architecture*
4.1.1 SciMyst 2007-2009

SciMyst is a CALS which takes the form of a treasure hunt game played in 2007-2009 at the annual SciFest science festival in Joensuu, Finland. Players of SciMyst used mobile phones to explore the festival arena and to solve enigmas related to the exhibitions and workshops. Each version of SciMyst has a special theme, and before the game starts the player is familiarised with the theme. The player can then choose to play alone or team up with friends or family members for collaborative exploration. All three versions of SciMyst use multiple-choice challenges and take-a-picture tasks in which the player must locate a specific object based on a given description and take a picture of a 2D bar code tag attached to it (see Figure 4.3). The player’s location is established by 2D bar codes as well. All correctly solved enigmas yield points for the player. At the end of the game the player has to complete the last challenge where the acquired knowledge is tested by repeating some of the game’s enigmas in a limited time. The game area is divided into coloured sections and the player is provided with a map of the area, including markers on the locations of workshops and area tags. If the player needs help with solving an enigma, they can use context help to receive a hint, contact other players through the multiplayer help feature of the game, or interact directly with the festival exhibitors. SciMyst also utilises the impression recording feature of the Myst platform to allow the player to capture memories of the festival. The game has also a website which presents all player-generated content. The concept and details of SciMyst are described in [38].

4.1.2 ADEMyst

ADEMyst is a treasure hunt game for promoting products and services of ADE Oy, a Finnish company specialising in 3D animations and visual design. After having seen SciMyst in action, the company representatives wanted to build a game on the Myst platform for promoting their business in a public relations event. A new game was build rapidly and showcased successfully during a one day event
Figure 4.3: SciMyst (2007) player recording a 2D bar code

in Helsinki in 2007. The game’s features were identical to those of SciMyst 2007 except the website which was omitted. This positive experience was the first indication that the platform could work in different contexts and for different purposes.

4.1.3 TekMyst

TekMyst is a game recontextualised from SciMyst for the Museum of Technology in Helsinki, Finland. One of the main motivations to create TekMyst was to test whether the SciMyst concept and technology could easily be ported to a different context, a space filled with machines and technological innovations. TekMyst is based on the SciMyst code but some game rules were changed, a mechanism for multiple game levels was added, and the user interface was customised. The TekMyst theme featured a magical kingdom of knowledge-sharing ants and their battle against ignorance and laziness which threatened the kingdom. The game was deployed and tested with several school groups during one week in August 2008.
More information about TekMyst, including its design process, is available in [39].

4.1.4 EdTechMyst

EdTechMyst is an application of the SciMyst concept to the Educational Technology research group’s (EdTech) laboratory at the University of Joensuu (now the Joensuu Campus of the University of Eastern Finland). The objective of the game is to familiarise a visitor with the EdTech group’s research activities and demonstrate the capabilities of the Myst platform at the same time. As with ADEMyst, EdTechMyst was created within a very short period of time and it has been demonstrated to various visitors to the research group since its emergence in 2008.

4.1.5 LieksaMyst

LieksaMyst is a CALS created for the open air Pielinen Museum in Lieksa, Finland. The concept of LieksaMyst differs from the aforementioned games because it is a suite of applications including a story-based game, a database discovery tool, an NFC-based knowledge retrieval tool (prototype) and a story editor. The story-based game is the most complex feature of the system and its concept also differs from earlier treasure hunt games. Whereas the aforementioned games are based on competitive quizzes, LieksaMyst offers a relaxed (no time limits, no competition) way to make a journey back in time to visit fictitious characters from the past who live in the museum buildings (see Figure 4.4). The characters tell the player how life is like in their respective periods of time, and ask for assistance in performing various daily activities such as weaving carpets or churning butter. Relevant sound effects are used to create an authentic atmosphere. Mobile phones are used for interacting with the character who ask the player various questions and ask them to locate specific museum objects. By embedding these objects into the story, the game teaches the player the usage of and the connections between the objects. The technology used in LieksaMyst is based on
the technology of previous games but modifications were needed in order to accommodate the story-based game structure and changes in the rules. However, these modifications were made while retaining the platform’s flexibility for the future game releases.

Currently, LieksaMyst has two stories in two locations: a story of Anna, a warm-hearted 40 year-old lady of the Virsuvaara house (the largest building in the museum) in 1895, and Jussi, a 30 year-old unmarried forest worker who lives in a forest camp in the 1930s and has manners comparable to lumberjacks of that time. More information about the LieksaMyst CALS and its design process is presented in [40].

4.1.6 UFractions

The last Myst-based game is UFractions (Ubiquitous Fractions) which was developed for students in South African rural middle schools. The development process of UFractions was financially and temporally constrained, and a decision was made to base it on the story-
Platforms for CALS

telling concept of LieksaMyst and mix it with competitive features of SciMyst. The game features a story of two leopards on a mobile phone and a set of colourful fraction rods (Cuisenaire rods) which are used to solve the challenges presented on the phone (see Figure 4.5). In the story the player’s task is to help a mother leopard and her cub through mathematical problem solving. For each correctly solved fraction challenge the player is rewarded points. The game has an introduction part, followed by three levels of varying difficulty of which the player can choose one or play all of them. In addition to the story, the game has a feature which allows the player to use the phone’s camera to record evidence of fractions from the real world and share this evidence with a comment on the game’s website. The game’s website also contains statistics related to players’ performance individually and collaboratively, and guest book entries that the players can submit at the end of the game play from the phones. The design process and the features of UFractions are described in detail in [87].

Figure 4.5: An example of a mathematical challenge in UFractions

UFractions was tested in South Africa (2009), in Finland (2010) and in Mozambique (2011). Consequently, the content has been made available in English, in Finnish and in Portuguese. A development
activity has also started towards the creation of intelligent fraction rods which are monitored in real time by the game so as to analyse the player’s actions and act upon them (e.g. instant feedback) [80]. This technology, however, has not yet reached its maturity and thus has not been evaluated with learners.

4.2 THE HOK PLATFORM

When the development of the Heroes of Koskenniska CALS commenced (see Section 4.2.1), the game concept was envisioned to be different to the Myst-based games in terms of context-awareness and content structure. In the Myst-based games, context-awareness is mostly based on detecting the locations of the users and the objects, and content is arranged according to pre-defined screen types within enigmas. In addition to detecting locations, Heroes of Koskenniska required deeper contextual information from the surrounding environment. Additionally, a more flexible content structure was required which would enable the designer to easily utilise existing screen types or create new ones.

Figure 4.6 presents the architecture of the HoK platform which is also based on the MUPE software. The content structure follows the Model-View-Controller architecture in which the data model (learning content) is separated from the view (representation of the content) and control (user input mechanisms). This way the same data can have alternative representations which, in turn, can have alternative input mechanisms. The HoK platform has also the ESN (Environmental Sensor Network) Manager (middleware) for handling incoming data from sensors deployed in the environment. The support for environmental sensor data adds another layer of context-awareness to the platform. More details about the HoK platform is available in paper IV which discusses the creation of the platform and the Heroes of Koskenniska game.
4.2.1 Heroes of Koskenniska

Heroes of Koskenniska is a CALS combining mobile and sensor technologies in a natural context to provide the means to raise environmental awareness among visitors of the Koskenniska Mill and Inn Museum area in North Karelian Biosphere Region\textsuperscript{1} in Eastern Finland. The area consists of four museum buildings, a sauna, a forest, a river and a lake. Readings from an Environmental Sensor Network [59] provide background data for the game where the player traverses the forest and the museum area while performing various learning activities. Figure 4.7 shows a team of two players in the forest area of Koskenniska. The player’s location is established by using riddles which are connected to specific locations and which must be solved before the game can be continued. The story of the game has references to the Finnish epic story Kalevala and it interweaves concepts such as the beginning of life, the afterlife, the meaning of time,

\textsuperscript{1}Part of UNESCO’s Man and the Biosphere Programme

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figures/figure46.png}
\caption{The HoK platform architecture}
\end{figure}
energy and animals. The game has three levels ordered by increasing difficulty. Each level has three Magic Spots specific to physical locations and themes. The player can freely choose the traversal order of the Magic Spots within a level. Each Magic Spot has a number of challenges which can be text-based multiple choice questions (with one or more correct answers), image-based tasks where the player must pick a correct image from several possibilities, or special spot activities in which the player must perform hands-on activities such as building a bark boat and taking a picture of it. Each challenge can have any number of screens which introduce the player to the challenge before the actual challenge screen. A more detailed account on the Heroes of Koskenniska game is available in paper IV and [50] describes the environmental sensor network implementation.

![Figure 4.7: Two players solving a challenge in Heroes of Koskenniska](image)

### 4.2.2 TekGuide and TekGame

TekGuide and TekGame are two applications that together form a CALS based in the Museum of Technology in Helsinki. The HoK
platform was chosen for creating these applications due to the higher degree of flexibility of content structure than that enabled by the Myst platform. The ESN Manager of the HoK platform is not used, but the platform was modified to introduce some new challenge types and rules that were not present in Heroes of Koskenniska. Both TekGuide and TekGame are operated with a mobile device which the visitor carries in the exhibition hall. TekGuide takes the visitor to a tour through the four thematic areas of the museum by using text, images and sound effects as well as audio narration. The visitor may choose their pace and go back and forth between the screens of information. Long texts can be scrolled and images zoomed to fill the entire screen. Sounds and narrations are played automatically, and the visitor can stop or repeat the audio at will.

TekGame is a more complex and interactive application than TekGuide. It is based on various objects embedded in the four thematic areas of the museum but the traversal order of these objects can be decided by the player. Thus, there is no forced chronological structure in TekGame as content created for each object forms an independent entity. For the time being there are 13 objects included in the game and for each object there are two challenges: one for knowledge and one for creativity. Compared to Heroes of Koskenniska, TekGame has a few new challenge types such as an ordering challenge in which the player sorts a list of items to some order. Additionally, there are Super Challenges with a higher degree of difficulty that are shown after every three passed objects. The selection of objects is done by recording 2D bar codes with the mobile phone’s camera. As the platform is the same for TekGuide and TekGame, the latter also utilises text, images and audio content. However, interaction is of higher degree in TekGame due to increased possibilities for user input. Unlike other CALSs presented in this chapter, TekGuide and TekGame have not yet been evaluated nor described in previous publications.
4.3 CHARACTERISTICS OF A REUSABLE CALS PLATFORM

Because CALSs can be created for many different contexts and purposes, there is a need for a flexible and reusable system architecture. Such an architecture can be measured through the aspects of viability and portability which are defined as follows (paper IV).

- **Viability**: the extent to which a given CALS can be adapted to the requirements of new stakeholders or a subject matter

- **Portability**: the extent to which a given CALS can be transferred to a new physical context without adjusting the technical implementation

If the architecture of a CALS allows flexible creation of new types of applications in the same physical context with minimal development efforts then the viability is high, whereas if a CALS is suited only for a single purpose the viability is low. A CALS has low portability if deployment to another location requires significant changes to the underlying system (e.g. rules, concepts, equipment). High portability allows a CALS to be transferred between physical contexts with minimal changes to the original implementation.

Portability is high in both platforms as neither of them have components fixed or dependent on the physical context. Viability of the Myst platform is not at a high level because of its limitations in the content structure representation and lack of a sensor data middleware component. In contrast, the HoK platform’s viability is higher as it remedies these shortcomings of the Myst platform. Furthermore, the successful creation process of the TekMyst 2 game has informed us that the HoK platform can be successfully applied to different purposes and contexts (i.e. from environmental education in a forest to history education in a museum).
5 Technology integration in CALS

As has been previously defined in Section 3.4, technology integration in a formal pedagogical context refers to the process by which a technology is introduced into a classroom to facilitate teaching and learning. In context-aware learning, technology integration can be seen as a challenge for CALS design, implementation and deployment. This is because CALS creators may not have the needed technical and conceptual knowledge and skills to choose and integrate technologies into the learning space. Without this know-how technology integration in a CALS will result in disturbed learning experiences. For example, a badly integrated technology may cause the learners to concentrate on playing with the properties of the technology instead of performing learning activities.

To my knowledge technology integration in CALSs has not yet been researched. Furthermore, research on technology integration in informal learning contexts has been overshadowed by the research on technology integration in formal classroom settings. The importance of proper technology integration is particularly high in CALSs where the technology plays a big role in contextualising the learning content. The iterative process of technology integration in a CALS is illustrated in Figure 5.1 (paper VII). The idea is that the first version of a CALS is placed under evaluation of technology integration. The results of the evaluation are utilised in the revaluation process which diminishes the problems discovered in the evaluation, thus increasing the pedagogical and motivational value of the CALS. Devaluation may take place when when a technology breaks or becomes obsolete. In this case revamping the CALS with a new technology is needed. After revamping a new evaluation should be performed to ensure successful integration of the new technology.

Waycott’s Tool Integration Process (TIP) model [90] was previously illustrated in Figure 3.5. We can compare the TIP model to the technology integration process shown in Figure 5.1. Waycott’s
model is user- and task-centric, and it aims at identifying new ways of using a mobile technology, such that were unforeseen by the designers. This information can be used to offer new opportunities for further technology integration and development. In contrast, the CALS technology integration process covers the entire cycle of technology integration from emergence to evaluation and from improvement to degeneration. The TIP model could be used to complement the CALS technology integration process by identifying new ways of using the CALS. However, since the TIP model was developed for the purpose of mobile learning, it may need to be adjusted to match the setting of context-aware learning. Such development is out of the scope of this research.

To tackle the challenge of technology integration in CALSs, the following sections present a model to describe requirements of technology integration and a tool for evaluating technology integration in CALSs.

5.1 TECHNOLOGY INTEGRATION MODEL

The proposed technology integration model, presented in paper V and illustrated in Figure 5.2, concerns various requirements which
Technology integration in CALS

should be met by the integrated technology. Each main requirements category (tips of the triangle) is further divided into more specific requirement categories. The context requirements cover the requirements and restrictions set by the context’s available resources, culture, technology, environment, social aspects and scheduling. The pedagogical requirements in this case are formed by a set of characteristics for pervasive learning spaces (a subset of CALS, see Section 3.3). These requirements cover categories of user profiles and perspectives, interaction and collaboration, ownership, authenticity and relevance, and support and assessment (paper II). Finally, the design requirements include subcategories of context-awareness, game dynamics, interaction, and content design. Each requirement category has a critical factor and they are: unobtrusive technology for the pedagogical requirements; available resources for the context requirements; and context-awareness for the design requirements.

Figure 5.2: Technology integration model for CALSs (critical factors marked with asterisks)

Paper VI continued the work on the technology integration model by dividing technology integration into passive and active components. This division was done according to the roles of technology in the integration process as follows.
1. *Passive integration*: technology must be integrated into the CALS so that it becomes subtle and unobtrusive to the learner and to the context. In other words, technology is the object of integration.

2. *Active integration*: technology must integrate the contextual resources and context-free resources into the CALS and make the system adaptive to the changing situations of the context, including users within. In other words, technology is the subject of integration.

This division is necessary in order to manage the technology’s direct and indirect influence on the learners. Both active and passive integration are driven (or restrained) by available resources (Figure 5.3). Passive integration aims at achieving unobtrusiveness of the technology from the learners’ and the context’s perspectives so that the learning process and the context will not be disturbed by the technology. The integrated unobtrusive technology is used to provide context-awareness to the active integration process via contextual resource detection. The goal of active integration is to establish context adaptation [51] within the system. This means that when the situation in the target context changes, the technology automatically adapts the contextual and context-free resources to the new situation.

In addition to passive and active integration, the requirements defined by the model and the critical factors can be used by a CALS designer to prepare and assess a plan for integrating technologies into a CALS. Once design and implementation have been completed, it is necessary to evaluate the outcome of the technology integration process. To verify the need for technology integration evaluation, the aspects of active and passive integration were applied to the evaluation of the UFractions game (see Section 4.1.6) in South Africa and in Finland. The tests were conducted with 105 and 104 eighth grade pupils in South Africa and in Finland respectively. The data set was designed for investigating the reverse transfer process of UFractions [51] where a technology, which was designed and developed in
and for a technology-alien context (South Africa), was transferred to a technology-familiar context (Finland). Relevant metrics of the data set were used so as to evaluate the direct and indirect influence of the technology on the pupils. The results, presented in paper VI, suggest that particularly active integration failed in the Finnish context as the technology indirectly influenced the pupils by not providing contextualisation of the game content. Passive integration was fairly successful as there were no technical issues and most pupils received the technology well, but there were some individual pupils whose learning processes were disturbed by the technology.

During the evaluation it was observed that the lack of active or passive integration may cause various disturbances to the learning process. These disturbances do not necessarily affect the majority of the test participants, hence a qualitative approach was required. By analysing the qualitative data from questionnaires, interviews and observations, sixteen disturbance factors were discovered which relate either to active (9) or to passive (7) integration of technology. Ta-
ble C.1 describes the disturbance factors with indications that map the relevant evidence to the factors. Column I indicates whether the factor relates to active (A) or passive (P) integration. Identified disturbance factors are grouped by the learner’s areas of experience which are affected by the disturbance factors. The disturbance factors “Below ZPD” and “Beyond ZPD” refer to Vygotsky’s Zone of Proximal Development [88].

5.2 TECHNOLOGY INTEGRATION EVALUATION TOOL

The technology integration evaluation shown in the previous section yielded interesting results. Particularly the identified disturbance factors are useful for guiding the improvement process of UFrations. However, as described above, the data set used was not designed for measuring technology integration in CALSs, hence calling for a dedicated tool for a deeper evaluation. For this purpose a technology integration evaluation tool was created (paper VII) by grounding it on the technology integration model and on the TPCK framework for classroom-based technology integration [48] (see Section 3.4). The evaluation tool uses the viewpoints of the learner, the educator and the context to measure the critical factors (unobtrusiveness of technology, availability of resources and context-awareness) as well as affordances and constraints (from the TPCK framework) in the target CALS. These aspects formed the basis of the evaluative questions for the viewpoints of the learner, (Table B.1), the educator (Table B.2) and the context (Table B.3). These questions are to be used as a starting point for creating data collection instruments. For example, the question “How do the learners perceive the technology?” can be answered by asking the learners’ opinions on and experiences with the technology (e.g. mobile devices) as a part of the CALS.

The evaluation tool also measures general perceptions of the CALS. These data include likes, dislikes, suggestions for improvements, motivation and applicability to other contexts. These aspects can be used to evaluate the attractiveness of the CALS as a learning tool both from the learner’s and the educator’s perspectives.
After creating the evaluation tool, an evaluation of UFractions was performed in the Mozambican context, and was targeted at 70 pupils at two schools in Maputo. Only the learner’s viewpoint was considered in this evaluation which is presented in detail in paper VII. Applied evaluation instruments are presented in Appendix D. As a result, 22 disturbance factors were identified which are described in Table C.2. The disturbance factors were derived using the same method as the evaluation described in Section 5.1.

All but one of the previously identified disturbance factors (16) can be found within the 22 disturbance factors discovered with the evaluation tool. Furthermore, the size of the data sets used in this evaluation (70) was significantly smaller than the combined data set used in the previous study in South Africa and Finland (209). The participants in Mozambique were of a wider age range (10-32, average 13) than in South Africa and Finland where UFractions was tested on eighth graders. Additionally, in Mozambique the participants were of 23 different nationalities, thus making the data heterogeneous. There was also a high number (75) of significant correlations (equal to or above 0.5) between quantitative statements of the questionnaire in Mozambique. This informs us of the good quality (triangulation) and the depth of the data. In contrast, in the South African data set the number of significant correlations was 8 and in the Finnish data set it was 29. These observations on the results indicate that the evaluation tool outperformed the previous evaluation as it produced more accurate results with a smaller data set. This suggests that the evaluation tool is likely to speed up the technology integration process of a CALS through a rapid evaluation procedure.
6 Discussion

By identifying the concept and the characteristics of CALSs, I have established the foundations on which researchers and educators can base their future efforts on learning environment developments towards richer and contextually relevant learning experiences. The definitions used in this dissertation aim at creating a common vocabulary for future work on CALSs. For example, previously the terms pervasive learning and ubiquitous learning have been used in some cases as synonyms but now they have well-defined meanings that differ from each other. Furthermore, my definition of context-awareness is generic enough to be used for other purposes apart from CALSs.

The iterative development processes of the Myst and the HoK platforms show the elements that a viable and portable platform for a CALS should contain. Successful design and implementation of ten game-based CALSs on the two platforms indicate that the proposed platforms can be used for many different contexts and purposes. A question remains whether the platforms would be suitable for a CALS without game-like features. To my understanding they would, as both platforms support flexible use of text, graphics and sounds to present the learning content. For example, instead of a quiz-like structure of SciMyst at the SciFest festival, the Myst platform could be used to create an interactive tour guide for the festival. However, I argue, with support from Malone [58], that it is through games that the learners, particularly children and young adults, can better immerse themselves in the flow [14] through increased intrinsic motivation. Hence, although the Myst platform and the HoK platform can be used for CALSs without game-like features, the gaming approach is recommended especially for young learners.

Technology integration has received much attention in the context of traditional classroom-based learning but in the domain of informal learning, particularly in context-aware learning, the issue has not received similar attention. While a CALS at its best can provide
highly interactive and engaging learning experiences, the technical complexity might be high, thus leading to issues of badly integrated technology. The technology integration model for CALS was created to assist CALS designers to choose and apply technologies based on various requirements set by the context, the pedagogy and the design. Technology integration was further divided into active and passive integration. Both integration types are important to consider, as was suggested by the evaluations of the UFractions CALS in three different contexts (papers VI and VII). Therefore, an important implication is that in order for a CALS to be pedagogically and motivationally effective, its technology must be unobtrusive and subtle to the learner while adapting contextual resources to match the learner’s profile and the context’s requirements.

The concepts of active and passive integration are generic enough to be applicable to other contexts as well. In a formal classroom-based pedagogical setting technology integration is usually performed in a passive manner, i.e. technology is introduced to the context with appropriate training for teachers and students. However, active integration could also be applied so as to make the technology in the classroom more responsive to the learners’ and the teacher’s preferences and background knowledge. For example, a new technology could provide a novice teacher with an extensive usage tutorial whereas a more technology-savvy teacher would be given access to advanced features of the technology. In a similar fashion, the active integration process could ensure that the students would receive learning materials in preferred formats and compatible with the students’ previous knowledge. This could be done for example by existing technologies used in intelligent tutoring systems [68] and content adaptation systems [52].

Based on the model of technology integration in CALSs, a tool was proposed for evaluating technology integration. Both the model and the evaluation tool are novel approaches to scrutinise technology integration in CALSs from an holistic perspective. The proposed evaluation tool connects to the TCPK model by Koehler and Mishra [48], thus building on firm theoretical foundations of technol-
ogy integration in classroom contexts. The evaluation tool was used to assess the UFractions game in the Mozambican context in order to measure the tool’s suitability for technology integration evaluation in CALSs. The evaluation conducted with the tool yielded deeper results with a significantly smaller data set than a previous evaluation without the tool (paper VI), hence indicating the efficiency of the tool.

The proposed technology integration evaluation tool is not perfect. It performed well with UFractions but its limits and opportunities with other CALSs are yet to be explored. Furthermore, the evaluation presented in paper VII did not consider the viewpoints of the educator and the context. Although the learner’s viewpoint is the most critical, it is necessary to consider these other viewpoints as well if comprehension of the big picture of technology integration in a CALS is desired. The current version of the tool aims at delivering an overall view of technology integration but in the future there may be a need for specialised evaluations. For this purpose, I suggest that a future version of the tool should have a suite of test instruments which are organised by areas of experiences (e.g. user experience, learning experience, social experience).

The evaluations of technology integration on the UFractions game (both with and without the evaluation tool) revealed disturbance factors which guide the improvement process of a CALS. The identified disturbance factors may indicate pitfalls in the design and implementation of future CALSs. This information is useful for CALS designers who can now plan the use of technology so that the goals of active and passive technology integration are met. Furthermore, the areas of experience, which were used to group the disturbance factors, are useful for the CALS designers for ensuring that a variety of different experiences are supported in a CALS. It is clear that there are more disturbance factors and areas of experience to be discovered by future studies. These results can be used as a starting point towards a complete taxonomy of experience areas and related disturbance factors. Additionally, generalisability of the factors and their experience areas to other learning environments apart from CALSs
should be investigated.

The results of a technology integration evaluation can be used to inform the revaluation process in which the identified problems and disturbances are diminished (Section 5). This important step towards improving technology integration in a CALS is left for future research. Assumptions can already be made on some aspects about the revaluation process. First, a taxonomy of potential solutions will be available with information on how each solution can help to diminish the disturbances. Secondly, there will be separate revaluation threads for active and passive integration because they have inherently different goals. Improving passive integration should be completed first because it may affect active integration through context-aware technologies. Thirdly, in the passive integration user experience [26] guidelines or similar tools can be used so as to decrease the obtrusiveness of the technology. Fourthly, in the case of active integration, content adaptation [52] could be a viable technology for ensuring the content’s suitability for a learner in a given situation.

Common sense dictates that by diminishing disturbance factors that were identified for UFractions, the game would better facilitate learning because the learner would be less distracted. However, determining the pedagogical effectiveness of a CALS goes beyond common sense and also beyond this dissertation. The results of this research can merely be used to develop CALSs and to evaluate technology integration in them. To effectively evaluate the learning experience in a CALS, the 18 pedagogical characteristics for CALSs (Appendix A) could be used as the basis for evaluation instruments. Additionally, it is necessary to use appropriate pedagogical assessment techniques for a given subject matter in a long term exposure. These results must then be compared to the results of a control group in order to determine how much the learners who use the CALS actually benefit from it. Another aspect that should be a subject to evaluation in addition to acquired knowledge and skills is motivation as it contributes to the overall learning experience and attitude towards the content matter.

Elimination of all problems and disturbances in a CALS is very
Discussion
difficult despite of the use of state-of-the-art context-aware technologies. This is because the more technology is used, the harder it becomes to manage the technical complexity and to make it unobtrusive to the learner. Furthermore, price of technology is an effective limitation in many projects and even if there would be infinite financial resources, it would not be possible for a system to be aware of everything within a context. For example, detecting the most fine-grained nuances of a human’s body and mind is currently not possible, and the physical environment with all its dimensions is a very complex structure to monitor in an holistic manner. The good news is that as the development of context-aware technologies advances and they become more affordable, it will be possible to create highly context-aware systems in financially constrained areas. These systems will converge towards Weiser’s vision on ubiquitous computing where technologies “weave themselves into the fabric of everyday life until they are indistinguishable from it” [92] while providing access to the richness of hidden resources of the surrounding contexts.
7 Conclusion

During 2007-2011, I was involved in the creation of ten context-aware learning spaces in versatile contexts and for different purposes, including but not limited to mathematics in South African and Mozambican schools, environmental awareness in a Finnish forest, history in an open air museum and a technology museum in Finland, and science at a science festival in Finland. Additionally, I spent one year in South Korea to become familiar with the state-of-the-art technologies, particularly sensors and wireless communications. The richness of contexts provided the research with opportunities that would not have been possible in a single context.

My role as a technical developer granted me a unique view over the challenges and the opportunities posed by the target contexts from a technical point of view. Each iteration of the exploratory software development process provided me with new ideas to narrow the focus of this research, which eventually led to the emergence of the concept and the characteristics of CALSs, a technology integration model and an evaluation tool for technology integration. These results fulfill the overall objective of this research which was to provide the developers with the tools for construction and evaluation of CALSs in which technologies have been integrated effectively so that they do not disturb the learner.

Research question Q1, “what features characterise context-aware learning spaces (CALSs) within the domain of mobile-based learning tools?”, was answered by a literature analysis on existing CALSs, state-of-the-art context-aware technologies and a number of pedagogical approaches for informal settings. In the process I defined the concept of CALS together with other interrelated concepts and derived a set of characteristics which can be used in a CALS design process as a checklist to increase the pedagogical value of the CALS. A challenge with this research question is that, due to the rapid development of technology, it is very laboursome to keep up-to-date with the latest...
technologies. Consequently, the current state-of-the-art technologies should be analysed for each CALS development project.

In research question Q2, “How can a CALS platform be constructed?”, the exploratory software development method was followed by which ten CALSs and two CALS platforms were created. Most of the CALSs were also evaluated. Without this practical work the other research questions would have never been formulated the way they are, thus this is the core part of this dissertation. The process started in the beginning of this research and is still ongoing. Based on the developing experiences, two concepts emerged which can be used to analyse CALS platform architectures: viability and portability. The descriptions of the CALSs, the platforms and the concepts, are useful for developers who want to establish their own flexible and reusable CALS platforms. A challenge with this research question relates to the challenge of Q1 – the rapid development of technology makes most platforms obsolete within a few years of its launch. However, high level architectural features (e.g. modular structure, Model-View-Controller pattern) can be applied across technologies.

The results of research questions Q1 and Q2 informed the research question Q3 (“How can technology integration be taken into account in the design phase of CALSs?”). As a result, I established a technology integration model which is partly based on the characteristics of CALSs and partly on an artefact analysis conducted on the CALSs which were created. The model suggests various requirements and three critical factors to be considered in order to facilitate smooth technology integration. The concept of technology integration was further divided into active and passive integration according to the role of technology in the process, and UFractions was evaluated from these perspectives. The established model is useful for CALS designers in order to ensure appropriate integration of technology.

The final research question Q4 was “How can technology integration in CALSs be evaluated?”. To answer this question, I created an evaluation tool based on the technology integration model (Q3) and a literature analysis on technology integration in formal educa-
Conclusion

The evaluation tool uses the three critical factors of the technology integration model as well as affordances and constraints to measure technology integration in a CALS from the perspectives of the learner, the educator and the context. Comparison of two evaluations indicated that the evaluation tool produces more accurate results with a smaller dataset than an evaluation conducted without the tool. Thus, the evaluation tool can be useful for CALS designers and developers who want to know how well technology is integrated into their systems.

There are several limitations to this research which could be addressed by future studies. First, although I established the characteristics for CALS, there is still no dedicated pedagogical model that could be used to facilitate the pedagogical appropriateness of a CALS. Future research could use the CALS characteristics as a starting point towards establishing such a model. Secondly, while both Myst and HoK platforms have certain degrees of viability and portability, their underlying technology is becoming rapidly outdated. This applies particularly to client devices: the current J2ME-based client implementation is no match to Android, MeeGo or iOS platforms in terms of features and programming capabilities. Thus, an important technical research and development project would be to add a multi-client support to the platforms or rebuild the platforms to support the latest mobile software platforms. Thirdly, the concepts of active and passive technology integration have only been discussed within the domain of CALS. An interesting future study would therefore be to find out how well these concepts could apply to other informal and formal learning environments. Fourthly, when the proposed technology integration tool was used on UFractions, only the learner’s role was considered. It is, therefore, important to apply the evaluation tool for the educator’s and the context’s roles too, as well as for other CALSs. Only this way can the generalisability of the evaluation tool be determined. Fifthly, this research proposed tools only for CALS creation and evaluation. The process of technology integration revaluation, i.e. diminishing disturbances and problems discovered in the evaluation, was only speculated upon in this dissertation, hence it
requires more work. Once a method or a tool for the revaluation process has been established, the overall iterative process of technology integration in CALS is completed. Finally, this research has set the foundations for the CALS implementation and technology integration processes. However, both of these processes can and should be explored further as I have merely performed an initial survey and much of this territory remains uncharted.

In the future we will see context-aware technologies as a more integral part of our lives. Already now, location-based services are popular and it is only a matter of time before these services will expand towards wider utilisation of contextual resources such as sensor data. Initiatives have already been launched to gather and manage global sensor data (e.g. SensorPlanet [8], SensorBase [12]) which can be used by researchers and developers to invent new ways of utilising the data in context-aware applications. This also applies to the field of education and I envision CALSs to be in the forefront of educational technology development as the importance of informal learning will be more acknowledged. In addition to sensing the surrounding context, future CALSs will also be able to observe the bodily functions of the learner and thereby sense the optimal moment to deliver educational materials, for example. Technologies such as natural user interfaces, 3D screens, micro projectors, and even cybernetic implants can be used to take the user experience to the next level. This all raises ethical concerns that must be investigated in future research.
Bibliography


[34] B. Hou, H. Ogata, M. Miyata, L. Mengmeng, Y. Liu, and Y. Yoneo. JAMIOLAS 3.0: Supporting Japanese mimicry and...


A Characteristics of CALSs

Table A.1 describes the characteristics of CALSs that were identified based on a literature analysis on pedagogical approaches such as situated learning, authentic learning, contextual learning, group-based learning, exploratory learning, problem-based learning and museum learning.

Table A.1: Characteristics of CALSs

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Literature</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>User profile and perspectives</td>
<td>[15, 22, 25, 29, 30, 42, 46, 84]</td>
<td>In order to support learners of various backgrounds, skills and interests, the CALS should provide access to various roles, perspectives and skill levels in an adaptive manner.</td>
</tr>
<tr>
<td>Consideration of background, prior knowledge and experiences</td>
<td>[22, 46, 73, 74, 76]</td>
<td>Prior knowledge and experiences should be taken into account in learning activities. For example, a first-time learner has different needs to a regular learner.</td>
</tr>
<tr>
<td>Consideration of learning styles</td>
<td>[9, 49]</td>
<td>Different learners prefer to learn in different ways. The CALS should support the variety of learning styles by offering alternative content and activities via multimodal learner interfaces.</td>
</tr>
<tr>
<td>Interaction and collaboration</td>
<td></td>
<td>Sharing experiences and facing challenges together facilitate effective learning.</td>
</tr>
<tr>
<td>Social negotiation and collaboration</td>
<td>[15, 22, 25, 28–30, 46, 61, 72, 73, 76, 84]</td>
<td>By exploring the environment through various senses the learner becomes more attached to it. This relates to the characteristic “Consideration of learning styles”.</td>
</tr>
<tr>
<td>Multimodal exploration of the environ-</td>
<td>[15, 42, 61]</td>
<td>Ownership of the learning process and outcome</td>
</tr>
<tr>
<td>ment and objects</td>
<td></td>
<td>Ownership affects directly to motivation to learn. Furthermore, having control over one’s own learning process is necessary for effective learning.</td>
</tr>
<tr>
<td>Ownership</td>
<td>[15, 22, 27, 28, 30, 42, 46, 61, 72, 76, 84]</td>
<td>In addition to increased motivation, owning the technology has direct consequences on the ability to use the technology effectively.</td>
</tr>
</tbody>
</table>

Continues on next page
### Characteristic | Literature | Rationale
--- | --- | ---
**Authenticity and relevance** |  |  
**Authentic context** | [22, 24, 29, 74] | Solving real world challenges cannot be taught effectively in an unauthentic setting. Authentic context is also important for deep immersion of the learner.  
**Authentic activities that have relevance to the real world** | [29, 30, 46, 61, 72, 73] | Connecting learning activities to the real world is an important part of making the meaning of concepts. Without real world relevance, the concepts remain abstract.  
**Compelling narrative to facilitate immersion** | [22, 25] | The CALS should employ a compelling narrative that helps the learner to immerse quickly in the authentic context.  
**Gained experiences integrated and applied across different subject areas** | [30, 33, 61, 78] | Knowledge can and should be transferred across disciplines. The CALS should allow generalisation and linkage of the knowledge to other contexts and subject areas.  
**Personal relevance** | [22, 24, 61, 73, 84] | Learning activities in the CALS should have personal relevance, so the learner is able to construct a personal meaning of a concept.  
**Unobtrusive technology** | [76, 91] | Technology should not distract the learner in the learning process. In the best case the learner does not even notice the existence of the technology and therefore can become fully immersed in the context.  
**Support and assessment** |  |  
**Scaffolding techniques** | [15, 25, 29, 46, 61, 72] | Support should be available when the learner needs it the most, and it should be faded out when the learner can face the challenges themselves.  
**Support for just-in-time reflection** | [22, 29, 30, 42, 46, 70, 72] | The CALS should offer possibilities for reflection while performing learning activities. During reflection new knowledge is linked to existing mental models and prepared for future linkages.  
**Support for post-reflection** | [70, 72] | The CALS should also support reflection after the learning activities have ended. This can be done for example with an interactive website through which the learner can retrace the learning process.  
**Immediate feedback** | [15] | The learner should be provided with immediate, choice-dependent feedback after each activity. This helps to maintain (intrinsic) motivation and orientation in the learning process.  
**Integrated, authentic assessment** | [29] [30] | Even though CALS are often deployed in informal learning contexts, sometimes assessment is necessary. In such cases the CALS should offer a possibility to perform assessment as part of the learning process.
B Evaluation Tool for Technology Integration in CALSs

The following tables present the evaluative questions for the technology integration evaluation tool. The questions are categorised by the viewpoints of the learner, (Table B.1), the educator (Table B.2) and the context (Table B.3).

Table B.1: Learner’s role in the evaluation tool

<table>
<thead>
<tr>
<th>Learner</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unobtrusiveness of technology</td>
<td><strong>How</strong> good is the user experience of the CALS?</td>
</tr>
<tr>
<td></td>
<td><strong>Does</strong> any of the used technologies distract the learner?</td>
</tr>
<tr>
<td></td>
<td><strong>How</strong> do the learners perceive the technology? (or do they perceive it at all?)</td>
</tr>
<tr>
<td>Availability of resources</td>
<td><strong>Do</strong> the learners afford using the system (if not free)?</td>
</tr>
<tr>
<td></td>
<td><strong>How</strong> does the CALS take into account the learner’s available time resources?</td>
</tr>
<tr>
<td></td>
<td><strong>Are</strong> the learners able to use the technology efficiently?</td>
</tr>
<tr>
<td></td>
<td><strong>What</strong> kind of connections can the CALS create between the learning content and previous experiences of the learners?</td>
</tr>
<tr>
<td>Context-awareness</td>
<td><strong>How</strong> does the CALS take into account the learner’s personal context (e.g. location in a room, previous knowledge, preferences)?</td>
</tr>
<tr>
<td></td>
<td><strong>How</strong> does the CALS take into account the social context of the user (e.g. other learners)?</td>
</tr>
<tr>
<td></td>
<td><strong>How</strong> does context-awareness take into account the learner’s cultural background?</td>
</tr>
<tr>
<td>Affordances</td>
<td><strong>How</strong> do the features of the CALS facilitate learning?</td>
</tr>
<tr>
<td>Constraints</td>
<td><strong>How</strong> do the features of the CALS restrict/prevent learning?</td>
</tr>
</tbody>
</table>
### Table B.2: Educator’s role in the evaluation tool

<table>
<thead>
<tr>
<th>Role</th>
<th>Questions</th>
</tr>
</thead>
</table>
| Unobtrusiveness of technology | **How** does technology related to the CALS affect the educator’s normal work?  
**How** good is the user experience of the CALS operating interface and maintenance tools? |
| Availability of resources    | **Are** the educator’s technical skills adequate for operating and maintaining the CALS?  
**How** does the educator’s content knowledge compare with the content in the CALS?  
**How** do the educator’s time resources match with required time for operating and maintaining the CALS?  
**How** is the maintenance of the CALS organised? |
| Context-awareness           | **How** does context-awareness support pedagogical goals set by the educator?  
**How** well does the CALS take into account learners’ backgrounds and prior experiences? |
| Affordances                 | **How** do the features of the CALS facilitate the educator’s work? |
| Constraints                 | **How** do the features of the CALS restrict/complicate the educator’s work? |
### Table B.3: Context’s role in the evaluation tool

<table>
<thead>
<tr>
<th>Context</th>
<th>Evaluation Questions</th>
</tr>
</thead>
</table>
| Unobtrusiveness of technology | **How** does the technology integration process consider the authenticity of the context?  
**How** does the technology affect the maintenance activities in the context?  
**How** is the CALS integrated into the context as part of the educators’ work description and as a permanent service (rather than a prototype)? |
| Availability of resources | **How** do the available financial resources compare with the requirements of the CALS development and maintenance?  
**How** sufficient is the quality/quantity of available information/learning content to support learning with the CALS?  
**How** well does the physical infrastructure support the CALS? |
| Context-awareness         | **To what** extent is the physical context detected by the CALS?                                           |
| Affordances               | **How** do the features of the CALS benefit the context’s operations?                                       |
| Constraints               | **How** do the features of the CALS restrict/complicate the context’s operations?                          |
C Disturbance Factors

Table C.1 and Table C.2 present the disturbance factors identified in two evaluations of the UFractions game: one without the evaluation tool and one with the evaluation tool. Further evidence of these evaluations can be found in Papers VI and VII, respectively.
### Table C.1: Disturbance factors found in the first evaluation of UFractions

<table>
<thead>
<tr>
<th>Area of experience</th>
<th>Disturbance factor</th>
<th>Indication</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social experience</td>
<td>Harassment</td>
<td>Group members disturbed gameplay</td>
<td>A</td>
</tr>
<tr>
<td>Learning experience</td>
<td>Below ZPD</td>
<td>References to easiness of challenges</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Beyond ZPD</td>
<td>References to difficulty of challenges</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Wrong age group</td>
<td>Suggestion to use the game for younger players</td>
<td>A</td>
</tr>
<tr>
<td>Behavioural</td>
<td>Wasting time by</td>
<td>Avoidance of answering wrong despite the lack of challenge</td>
<td>A</td>
</tr>
<tr>
<td>experience</td>
<td>pleasing others</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emotional</td>
<td>Disturbing content</td>
<td>References to shocking or disturbing events in the content</td>
<td>A</td>
</tr>
<tr>
<td>experience</td>
<td>Too much story</td>
<td>References to too long story or too much reading</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Monotony</td>
<td>References to repetition or monotony of the content</td>
<td>A</td>
</tr>
<tr>
<td>Immersion experience</td>
<td>Inappropriate</td>
<td>References to poor graphics or suggestions to improve them</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>graphics</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inappropriate</td>
<td>References to poor sounds or suggestions to improve them</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>sounds</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lack of animation</td>
<td>References of lack of animation or suggestions to add them</td>
<td>P</td>
</tr>
<tr>
<td>Cognitive experience</td>
<td>Inconvenient</td>
<td>References to negative experience of using the rods</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>interaction with</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>rods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contextual</td>
<td>Unclear instructions</td>
<td>References to unclear tasks or difficulty of understanding them</td>
<td>A</td>
</tr>
<tr>
<td>User experience</td>
<td>Inconvenient</td>
<td>References to negative experience of physical handling of or properties of the</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>interaction with</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>phone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Small screen</td>
<td>References to small screen size or difficulty to see the content</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Technical faults</td>
<td>References to technical problems during playing</td>
<td>P</td>
</tr>
</tbody>
</table>
### Disturbance Factors

**Table C.2: Disturbance factors found in the second evaluation of UFractions**

| Area of experience | Disturbance factor          | Indication                                                      | I |
|--------------------|----------------------------|                                                                |   |
| Temporal experience| Too long game              | References to a long game or a suggestion to make it shorter   | A |
|                    | Too short game             | References to a short game or a suggestion to make it longer    | A |
| Learning experience| Beyond ZPD                 | References to difficulty of challenges                         | A |
|                    | Below ZPD                  | References to easiness of challenges                           | A |
|                    | Wrong age group            | Suggestion to use the game for younger players                 | A |
|                    | Lack of scaffolding        | References to getting stuck                                    | A |
|                    | Conflicting content        | Conflict between own idea and game’s idea                      | A |
| Immersion experience| Too much story             | References to too long story or too much reading               | A |
|                    | Monotony                   | References to repetition or monotony of the content            | A |
|                    | Too educational            | References to the game being too pedagogical                   | A |
| Social experience  | Harassment                 | Group members disturbed game play                               | A |
|                    | Lack of peer support       | References to lack of support from peers                       | A |
| Emotional experience| Disturbing content         | References to shocking or disturbing events in the content    | A |
|                    | Punishment                 | References to dislike on getting questions wrong               | A |
| Cognitive experience| Lack of animation          | References of lack of animation or suggestions to add them     | P |
|                    | Inappropriate graphics     | References to poor graphics or suggestions to improve them     | P |
|                    | Inappropriate sounds       | References to poor sounds or suggestions to improve them       | P |
| Contextual experience| Inconvenient interaction with rods | References to negative experience of using the rods             | P |
| User experience    | Inconvenient interaction with phone | References to negative experience of physical handling of or properties of the phone | P |
|                    | Technical faults           | References to technical problems during playing                | P |
|                    | Small screen               | References to small screen size or difficulty to see the content| P |
|                    | Unclear instructions       | References to unclear tasks or difficulty of understanding them| A |
D Evaluation Instruments

The following pages describe the evaluation instruments that are based on the technology integration evaluation tool and that were applied in paper VII to evaluate UFractions game in Mozambique. The evaluation was conducted on the role of the learner. First the pre- and post-test questionnaires are presented after which follows the interview questions.
University of Eastern Finland researchers have been developing a mobile game UFractions for learning fractions in a fun way. To see how well UFractions suits for you we have prepared this questionnaire. We kindly ask you to answer the questions as honestly as possible and enjoy your time with the game. All answers will be handled anonymously and identity information will be removed from published results.

Please answer the BEFORE PLAYING part before you start playing, and the AFTER PLAYING part after you have finished and returned the phone to us. Thank you for your time and don't hesitate to ask if you have any questions about this questionnaire or the game.

BEFORE PLAYING

1. Demographics

| Your name: |  |
| Date: |  |
| School: |  |
| Ethnic group and language: |  |
| Gender: | □ Male □ Female |
| Age: |  |
| Occupation: |  |
| Team name (in the game): |  |

2. Background – mobile device usage

a) Do you have a mobile phone? □ No □ Yes (if No, go to section 3)

b) Estimate how much you use the following functions of your phone (mark with X):

<table>
<thead>
<tr>
<th>Function</th>
<th>Several times a day</th>
<th>Once a day</th>
<th>Once a week</th>
<th>Once a month or less</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) SMS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ii) Talking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>iii) Taking photos</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>iv) Multimedia message (MMS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v) Playing music</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vi) Playing games</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vii) Chatting (e.g. MSN)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>viii) Social media (e.g. Facebook)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ix) Browsing internet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x) Calendar/alarm clock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>xi) Other (what):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Background – games and math

a) What kind of games do you usually play and what do you like about them?
b) How do you feel about math (what emotions do you feel)?

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

c) Do you find fractions difficult? Why/why not?

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Now go to play and have some fun!
AFTER PLAYING

4. Game experience

a) What did you like or enjoy about the game?


b) What did you dislike or find difficult in the game?


c) Did you find out anything surprising when you were playing the game? What was it?


d) How would you suggest to improve the game?


e) Rate the following features of the game:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Very boring</th>
<th>Boring</th>
<th>Neither boring nor interesting</th>
<th>Interesting</th>
<th>Very interesting</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Fractions theory</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>b) Playing with fraction rods</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>c) Solving questions with rods</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>d) Controlling the pace of the game</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>e) Story of leopards</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>f) Taking pictures</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>g) Writing to guest book</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

f) Which of these game activities did you like?

<table>
<thead>
<tr>
<th>Activity</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>No opinion</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) I liked playing with the fraction rods</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>b) I liked answering the questions</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>c) I liked interacting with leopards</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>d) I liked reading the story</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>e) I liked using the mobile phone</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
5. **Motivation**
While playing the game, what was the reason for you to keep on playing (what motivated you)?

<table>
<thead>
<tr>
<th>Motivation</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>No opinion</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) I wanted to know what will happen next</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>b) I wanted to know what will happen in the story</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>c) I wanted to save the leopards</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>d) I was curious to see what I can learn about mathematics</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>e) I wanted to solve all questions correctly</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>f) I wanted to play more with fraction rods</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>g) I wanted to learn more about leopards</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>h) I wanted to learn more about fractions</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

6. **Usability**
What are your opinions about the following statements?

<table>
<thead>
<tr>
<th>Usability</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>No opinion</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Using phone was familiar to me</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>b) Mobile device disturbed my playing</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>c) Networking errors disturbed my playing</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>d) Fraction rods disturbed my playing</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>e) The screen was too full</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>f) It was easy to use the phone as a tool for playing</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>g) Game helped me when I got stuck</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>h) Language was easy to understand</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>i) Questions were easy to understand</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>j) Story was easy to understand</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

7. **Clarity of the screen**
Rate the following aspects of the screen from “very unclear” to “very clear”.

<table>
<thead>
<tr>
<th>Clarity</th>
<th>Very unclear</th>
<th>Unclear</th>
<th>Neither unclear nor clear</th>
<th>Clear</th>
<th>Very clear</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Screen layout</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>b) Text</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>c) Graphics</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>d) Sounds</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>e) Navigation</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>f) Codes (e.g. “W” or “BL”) on fraction rods</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

8. **Context-awareness**

<table>
<thead>
<tr>
<th>Context-awareness</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>No opinion</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Story was suitable for Mozambique</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>b) Story was useful to me</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
c) Questions were suitable for my skill level | 1 | 2 | 3 | 4 | 5
---|---|---|---|---|---
d) Story was suitable to me | 1 | 2 | 3 | 4 | 5
e) I enjoyed playing together with my friends | 1 | 2 | 3 | 4 | 5
f) Finding correct rods was difficult | 1 | 2 | 3 | 4 | 5

9. Available resources

a) How much time do you think is enough to play this game? ________________________________

b) How much would you be willing to pay for playing this game? _____________________________

c) Please answer the following statements:

<table>
<thead>
<tr>
<th></th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>No opinion</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) It was easy to play from the beginning</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>b) I was able to relate the game events to my own previous experiences</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>c) Game was too long</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>d) Game was too short</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

10. Overall experience

<table>
<thead>
<tr>
<th></th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>No opinion</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Compared to a math class this was exciting</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>b) The game helped me to learn many new things</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>c) The game made learning fractions difficult</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>d) The game disturbed my learning</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>e) After this day I find fractions more interesting than before</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>f) I will think of leopards from now on whenever I do fractions</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>g) I would also like to meet other animals in the game and help them</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>h) I felt important as I was saving the leopards</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>i) It was fun to play with the phone</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

11. Final comments

Please write here your last comments of the game or send greetings to leopards:

Thank you so much for your help!
APPENDIX B – Interview questions for end users

1. Demographics

Name: 
School: 
How long have you known each other?

2. Questions

Affordances and constraints
1. Did you learn something new in the game? What was it?
2. What surprised you in the game?
3. Were there any part in the game that you found interesting/boring? Why?
4. What are the advantages/disadvantages of using the game instead of a normal math class?
5. What do you think are the benefits of this game?
6. Which part of the story did you (dis)like? Why?
7. Which challenge/task did you (dis)like? Why?

Critical factors
8. What do you think about using a mobile game for learning fractions at school or at home?
9. What do you think about using fraction sticks as part of the game?
10. Which technology caught your attention and why?
11. Did you have any problems with the mobile device? If yes, what kind of problems did you experience?
   - Basic usage?
   - Navigation?
   - Graphics?
   - Layout?
   - (Communication) Errors in the game?
12. How did the tasks and the story suit to each location where you were playing? How can this aspect be improved?
13. Did the game events reminded you about something that you have experienced in the past? What was it?

Suggestions for improvements
14. How would you change the game to make it more fun/interesting?
15. Imagine yourself in the time 20 years from now. How do you think this game is now compared to what it was 20 years ago (i.e. today)?


Matikka, Hanna. The effect of metallic implants on the RF energy absorption and temperature changes in tissues of head: A numerical study, 2010.

Xiaoguang, Qi. Studies on value sharing for derivatives and difference operators of meromorphic functions, 2010.


Yang, Congli. Studies on warphi-Bloch functions and different type operators between Qk spaces, 2010.


Kamppuri, Minna. Theoretical and methodological challenges of cross-cultural interaction design, 2011.


Vatanen, Tero. Multi-leaf Collimation of Electron Beams with Monte Carlo Modelling and Dose Calculation: Special Reference to Dosimetry and Build-up Dose, 2011.

Saeidi, Rahim. Advances in front-end and back-end for speaker recognition, 2011.

Nivalainen, Ville. Pre-service teachers’ objectives, challenges, and experience of practical work, 2011.

Mohaibes, Mohammed. Treatment and hygiene of farm slurry and food waste, 2011.

Viren, Tuomas. Arthroscopic ultrasound imaging of articular cartilage, 2011.


Haapio, Topi. Improving effort management in software development projects, 2011.

Tuomainen, Marjo. Search for molecular mechanisms related to Zn accumulation and tolerance in Thlaspi caerulescens, 2011.

Gröhn, Janne. Results on complex differential equations in the unit disc, 2011.

Li, Xiao-Min. Uniqueness results of difference operators and shifts of meromorphic functions, 2011.

Kuivalainen, Kalle. Glossmeters for the measurement of gloss from flat and curved objects, 2011.


Niskanen, Heidi. Modelling of fibre orientation in contracting channel flows and in the jet-to-wire impingement, 2011.


Saarelainen, Markku. Teaching and learning of electric and magnetic fields at the university level, 2011.


Roivainen, Päivi. Characteristics of soil-to-plant transfer of elements relevant to radioactive waste in boreal forest, 2011.

Haapala, Jaana. Mire plants and carbon dioxide dynamics un-
der increased tropospheric ozone concentration and UV-B radiation, 2011.


Technology Integration in Context-Aware Learning Spaces

Context-aware learning spaces (CALSs) are mobile-based learning environments which utilise contextual resources, such as real world objects, in the learning process. This dissertation presents the development of two technical platforms on which ten CALSs were created in 2007-2011. Based on the development experiences, a model and an evaluation tool for technology integration in CALSs are proposed. These results, both practical and theoretical, can be utilised by developers to create CALSs in which technologies have been integrated effectively so that they do not disturb the learner.