# Designing Intelligent Support for Learning *From* and *In* Everyday Contexts

## Dissertation

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# Abstract

Motivation and engagement in learning benefit from a good match of learning settings and materials to individual learner contexts. This includes intrinsic context factors such as prior knowledge and personal interests but also extrinsic factors such as the current environment. Recent developments in adaptive and intelligent technology enable the personalisation of context-aware learning. For example, computer vision algorithms, machine translation, and Augmented Reality make it possible to support the creation of meaningful connections between learners and their context. However, for successful adoption in everyday life, these technologies also need to consider the learner experience.

This thesis investigates the design of personalised context-aware learning experiences through the lens of ubiquitous and self-directed language learning as a multi-faceted learning domain. Specifically, it presents and discusses the design, implementation, and evaluation of technology support for learning *in* and *from* learners' everyday contexts with a strong focus on the learner perspective and user experience. The work is guided by four different roles that technology can take on in context-aware ubiquitous learning: For enhancing learning situations, it can (1) sense and (2) trigger *in* learners' everyday contexts. For enhancing learning contents, it can (3) augment activities and (4) generate learning material *from* learner everyday contexts.

With regards to the *sensing* role, the thesis investigates how learners typically use mobile learning apps in everyday contexts. Activity and context logging, combined with experience sampling, confirm that mobile learning sessions spread across the day and occur in different settings. However, they are typically short and frequently interrupted. This indicates that learners may benefit from better integrating learning into everyday contexts, e.g. by supporting task resumption.

Subsequently, we explore how this integration could be supported with intelligent *triggers* linked to opportune moments for learning. We conceptualise and evaluate different trigger types based on interaction patterns and context detection. Our findings show that simple interactions (e.g. plugging in headphones) are promising for capturing both availability and willingness to engage in a learning activity. We discuss how similar interaction triggers could be adapted to match individual habits.

In the area of enhancing learning contents, we first investigate how enjoyable everyday activities could be *augmented* for learning without disrupting these activities. Specifically, we assess the learner experience with interactive grammar support in e-readers and adapted captions for audio-visual media. Participants in our studies felt that the learning augmentations successfully supported their learning process. The information load of the learning support should match the learners' current needs to maintain the activity flow. Learners may need encouragement to opt for novel concepts optimised for learning (e.g. time-synchronised captions) rather than sticking to habits (e.g. standard captions).

Next, the thesis explores learner needs and preferences in *generating* their own personalised learning material from their context. We design and evaluate automated content generation methods that generate learning opportunities from objects in the learner's environment. The connection to the learner's context is established with state-of-the-art technology, such as

object detection and Augmented Reality. Through several user studies, we show that learning performance and engagement with auto-generated personalised learning material is comparable to predefined and manually generated content. Findings further indicate that the success of personalisation depends on the effort required to generate content and whether the generation results match the learner's expectations.

Through the different perspectives examined in this thesis, we provide new insights into challenges and opportunities that we synthesise in a framework for context-aware ubiquitous learning technology. The findings also have more general implications for the interaction design of personalised and context-aware intelligent systems. Notably, for the auto-generation of personalised content, it is essential to consider not only correctness from a technological perspective but also how users may perceive the results.

# Zusammenfassung

Lernmotivation und Engagement profitieren davon, wenn Lernumgebungen und Lernmaterialien auf den individuellen Kontext der Lernenden abgestimmt sind. Dieser umfasst sowohl intrinsische Faktoren wie Vorkenntnisse und persönliche Interessen, aber auch extrinsische Faktoren wie die aktuelle Umgebung. Aktuelle Weiterentwicklungen im Bereich adaptiver und intelligenter Technologien ermöglichen es, Lernen kontextbewusst zu personalisieren. So können mithilfe von Computer-Vision-Algorithmen, maschineller Übersetzung und Augmented Reality sinnvolle Verknüpfungen zwischen Lernenden und ihrem Kontext geschaffen werden. Allerdings müssen diese Technologien für einen erfolgreichen Einsatz im Alltag auch die Lernerfahrung mit einbeziehen.

Diese Arbeit untersucht die Gestaltung personalisierter kontextbewusster Lernerfahrungen aus der Perspektive des ubiquitären und self-directed Learning im Sprachenlernen, einem vielseitigen Lernbereich. Insbesondere wird die Konzeption, Implementierung und Evaluierung von Technologieunterstützung für das Sprachenlernen in und aus dem Alltagskontext der Lernenden vorgestellt und diskutiert, wobei der Schwerpunkt auf der Perspektive der Lernenden und der Nutzererfahrung liegt. Die Arbeit orientiert sich an vier verschiedenen Rollen, die Technologie im kontextbewussten Lernen einnehmen kann. Um Lernsituationen anzureichern, kann Technologie *im* Alltagskontext von Lernenden (1) erfassen und (2) auslösen. Um Lerninhalte anzureichern, kann Technologie *aus* dem Alltagskontext (3) Aktivitäten augmentieren und (4) Inhalte generieren.

Im Hinblick auf die *erfassende* Rolle von Technologie wird in dieser Arbeit untersucht, wie die Lernenden mobile Lern-Apps in alltäglichen Kontexten nutzen. Die Aufzeichnung von Aktivitäten und Kontexten in Kombination mit Experience Sampling bestätigt, dass Lerneinheiten im mobilen Lernen über den Tag verteilt sind und in verschiedenen Umgebungen stattfinden. Allerdings sind sie in der Regel kurz und werden häufig unterbrochen. Dies deutet darauf hin, dass die Lernenden von einer besseren Integration des Lernens in ihren Alltagskontext profitieren könnten, z. B. durch Unterstützung des Wiedereinstiegs nach einer Unterbrechung.

Anschließend untersuchen wir, wie diese Integration durch intelligente *Trigger* unterstützt werden könnte, die mit passenden Lernzeitpunkten verknüpft sind. Wir konzipieren und evaluieren verschiedene Arten von Triggern auf Basis von Interaktionsmustern und Kontexterkennung. Unsere Ergebnisse zeigen, dass einfache Interaktionen (z. B. das Einstecken von Kopfhörern) vielversprechend dafür sind, sowohl die Verfügbarkeit als auch die Bereitschaft für eine Lernaktivität zu erfassen. Wir diskutieren, wie ähnliche Interaktionstrigger an individuelle Gewohnheiten angepasst werden können.

Im Bereich der *Augmentierung* von Lerninhalten untersuchen wir zunächst, wie unterhaltsame Alltagsaktivitäten für das Lernen aufbereitet werden können, ohne diese Aktivitäten zu beeinträchtigen. Konkret bewerten wir die Lernerfahrung mit interaktiver Grammatikunterstützung in E-Readern und angepassten Untertiteln für audiovisuelle Medien. Die Teilnehmer:innen unserer Studien fanden, dass die Lernunterstützung ihren Lernprozess erfolgreich förderte. Die Informationslast im Lernsystem sollte auf die aktuellen Bedürfnisse der Lernenden angepasst

werden, damit das Flow-Erlebnis nicht beeinträchtigt wird. Die Lernenden brauchen möglicherweise Ermutigung dafür, sich für neuartige, lernoptimierte Konzepte zu entscheiden (z. B. zeitsynchrone Untertitel), anstatt an Gewohnheiten festzuhalten (z. B. Standarduntertitel).

Als Nächstes werden in dieser Arbeit die Bedürfnisse und Präferenzen der Lernenden bei der *Erstellung* ihres eigenen personalisierten Lernmaterials aus ihrem Kontext untersucht. Insbesondere werden Methoden zur automatischen Generierung von Inhalten entwickelt und evaluiert, die Lernmöglichkeiten aus Objekten in der Umgebung des Lernenden generieren. Die Verbindung zum Kontext des Lernenden wird durch aktuelle Technologien wie Objekterkennung und Augmented Reality hergestellt. Wir zeigen anhand mehrerer Nutzerstudien, dass die Lernleistung und das Engagement bei automatisch personalisiertem Lernmaterial mit vordefinierten und manuell erstellten Inhalten vergleichbar sind. Die Ergebnisse zeigen außerdem, dass der Erfolg der Personalisierung vom Aufwand abhängt, der für die Erstellung der Inhalte erforderlich ist, und davon, ob die generierten Materialien den Erwartungen der Lernenden entsprechen.

Die verschiedenen Perspektiven, die in dieser Arbeit untersucht werden, bieten neue Einblicke in Herausforderungen und Möglichkeiten, die wir in einem Framework für kontextbewusste ubiquitäre Lerntechnologie zusammenfassen. Die Ergebnisse haben auch allgemeinere Auswirkungen auf die Gestaltung der Interaktion mit personalisierten und kontextbewussten intelligenten Systemen. Beispielsweise ist es bei der automatischen Generierung personalisierter Inhalte wichtig, nicht nur die Korrektheit aus technologischer Sicht zu berücksichtigen, sondern auch, wie die Nutzer die Ergebnisse wahrnehmen.

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# Contents

# 1 Introduction

We are all learners of sorts. Even, and in fact, particularly outside of classrooms and curricula, we constantly readjust our mental model of the world and adapt our behaviour accordingly. For instance, we learn a new programming language, get used to bureaucratic processes at our workplace, and improve our yoga poses. Most of these learning processes are highly individual—each learner has their own reasons, motivations, and goals that stem from their own lives and experiences. They are also strongly tied to a learner's physical and cognitive context, which serves both as an incentive to engage in learning and as a basis for long-lasting associations [62].

Context-aware ubiquitous learning technology has the potential to create and support such ties between learners and their context by creating and adapting learning situations and learning materials [48, 62]. For example, mobile learning apps can turn a bus ride into an opportunity for vocabulary revision [93, 98]. Adaptive captions allow learning a language with one's favourite TV show [71]. And Augmented Reality (AR) supports exploratory learning by superimposing learning material onto our personal environment [24, 49].

Past work has already explored context-aware learning approaches such as location-based vocabulary learning [26, 37], using elevator wait times for microlearning sessions [12], embedding grammar exercises into website [70], and adapting learning paths based on past performance [82].

The primary focus so far has been on the technological feasibility and short-term learning effects, showing positive effects of context-aware learning technology [62, 122]. However, for the successful long-term adoption of such technologies, it is also crucial to consider the users' perspective [113]. Learners will only use a system if it satisfies their needs without taxing them; interaction patterns need to be well-designed for their goals and interests, and they should feel encouraged to engage.

## 1.1 Main Contributions

This thesis addresses learner perspectives in context-aware ubiquitous learning on the basis of self-directed language learning as our core application example. Specifically, we investigate how learners learn in everyday life and how we can adapt learning to their contextual needs, both in terms of *learning situations* (learning *in* everyday contexts) and *learning material* (learning *from* everyday contexts). To this end, we conduct user research, develop context-aware ubiquitous learning systems that apply state-of-the-art intelligent and adaptive algorithms to generate rich learning experiences, and evaluate the systems in empirical studies. Thus, we show how ubiquitous technology can serve as a bridge, or mediator, between the learner and their context and synthesise technology's respective roles as a guiding framework. The main findings and contributions of the papers included in this thesis are summarised in Table 1.1.

## 1.2 Structure of this Thesis

The remainder of this thesis is structured as follows: Chapter 2 lays out the landscape of relevant research to date, explains key terms, and defines the domain where we position the thesis contributions. Chapter 3 outlines the core challenges and derives the research questions. Chapter 4 summarises and assesses the research paradigms and methods we applied to arrive at

**Table 1.1 Research focus and findings, methods, and technology of the publications contributing to this thesis.**

| Publication | | Contributions & Main Findings | Evaluation Methods (Formative & Summative) | Technology |
|---|---|---|---|---|
| | | RQ 1: When, where, and how do mobile learners study in everyday contexts? | | |
| [P1.1] | Why did you Stop? | Mobile learners study in various contexts: at home and on the go. Learning sessions are typically short and are frequently interrupted. | 4-week field study ($n$ = 12) using the Android app (including experience sampling) | Custom Android app with activity logging and ESM notifications |
| [P1.2] | Task Interruption Support | We classify types of interactions and propose different concepts that could help mobile learners resume learning after an interruption. | 2 focus groups (HCI experts and mobile learners) | – |
| | | RQ 2: How can we link opportune learning moments with context-aware learning triggers? | | |
| [P2.1] | Agenda and Headphone Triggers | We explore two examples of context- and activity-based triggers that help learners identify opportune moments for learning and give recommendations for trigger design. Agenda-based triggers indicate availability, but only through activity patterns such as headphone plugin events are we also able to capture willingness to engage. | (1) Online survey ($n = 83$); (2) Within-subject four-week field study ($n$ = 10) using the adapted Anki app; (3) Between-subject two-week field study ($n$ = 8) using the AscoltaMicro app | (1) Adapted version of Anki app with Calendar access; (2) Custom Android app with headphone trigger |
| [P2.2] | Tagged Revision | We propose a place-based reminder app that automatically triggers the revision of learning content at marked locations with NFC tags. | – | Custom Android app with NFC reader |
| | | RQ 3: What are learner needs and preferences in the augmentation of everyday activities for enabling learning? | | |
| [P3.1] | Grammar in e-readers: UX | Based on a user-centred design process, we propose four concepts for grammar augmentations in e-reader interfaces. We show that case-based support with on-demand details is promising for the user experience and perceived learning. | (1) 2 focus groups (teachers and HCI students); (2) Within-subject lab study ($n = 16$) | Click prototype on tablet |
| [P3.2] | Grammar in e-readers: Flow | Based on [P3.1], we iterate on the proposed grammar augmentations and evaluate the effect of information load on reading flow, usefulness, and usability. The study shows that readers can often maintain reading flow with augmentations. Designs should be adaptive to focus on learning or engagement. | Within-subject lab study ($n = 24$) | Click prototype on tablet |
| [P3.3] | Enhanced Closed Captions | In a user-centred design process, we assess learners' needs and preferences for closed caption variants tailored to learning. We implement a processing pipeline for captions, including target highlights and time synchronisation. The study shows a trade-off between perceived usefulness for learning and supporting habits. | (1) Online survey ($n$ = 61); (2) Focus group (language learners); (3) Within-subject online study ($n$ = 49) | Custom srt files with styling, created with forced alignment & keyword filtering |
| | | RQ 4: What are learner needs and preferences in the auto-generation of personally relevant learning material from learner contexts? | | |
| [P4.1] | AR for Case Grammar: Learning & Interaction | Object-based AR for learning case grammar does not improve recall and engagement in comparison to static images, but it enables exploration-focused usage scenarios, which suggests that combining AR with static images for revision is promising. | Between-groups lab study ($n = 25$) | Custom Android app with marker-based AR-Core object detection |
| [P4.2] | AR for Case Grammar: Technology | Instead of AR markers, we extend [P4.1] with in-app offline object detection. | – (technical evaluation not published) | Custom Android app based on Tensorflow object detection demo |
| [P4.3] | Off-the-Shelf AI for Multimedia Learning Materials | We explore using off-the-shelf intelligent algorithms to produce multimedia learning material. The study shows that the redundancy of images and words provides reliability, but misspellings and blurry images are major challenges for children as learners. Auto-generation did not improve performance and engagement in comparison to static material. | One-week between-groups field study with children ($n = 25$), including final interview | Custom Android app with server for image analysis, translation, image retrieval, and logging |
| [P4.4] | Learner Perspectives on Context-Aware Auto-Generation | Context-aware auto-generation of learning materials based on photos learners take achieves comparable performance and engagement as manually generated material. However, when materials are personalised, they are rated worse than when they are not, which means that the expected benefits of personalisation were not achieved. We recommend considering learner efforts, expectations, and AI errors to mitigate impacts. | Two-week between-groups field study ($n = 64$) | Custom Android app with server for image analysis, translation, and logging |

the contributions presented in Chapter 5. Chapter 6 synthesises our contributions in a framework of ubiquitous technology for context-aware learning. Chapter 7 positions our work in the broader perspective of context-aware ubiquitous learning and discusses key considerations, such as implications for human-AI interaction in the learning domain. Chapter 8 lists my and my collaborators' contributions to the published papers. Finally, Chapter 9 briefly wraps up the presented contributions and provides an outlook.

# 2 Background and Definitions

The type of learning activity that we focus on in this thesis is self-directed, interest-based, and ubiquitous. Moreover, through the connection to the learner context, it is also context-aware and personalised. This section starts by examining the connection between learning and the real world and the role of motivation and interest in learning, which are closely linked to personal relevance. I then provide an overview of cognition in learning and the implications for designing successful learning experiences. I present related work on embedding technology into everyday-life contexts. Finally, I explain why we opted for context-aware and self-directed ubiquitous language learning experiences as the application scenario explored in our contributions.

## 2.1 Connecting Learning to Learning Contexts

The learner context and its connection to learning targets play a key role in learning [48, 62]. For instance, learning how to order a coffee in a foreign language while sitting in a café seems more effective than learning the same at home because learners can establish a meaningful association with the real world. Research on memory and learning supports this intuition to some extent. Below, I explain how we understand *context* in this thesis. Then, I summarise key research on the benefits and limits of the learner-context relationship. This includes work on human cognition as well as learning theories and strategies.

### 2.1.1 Our Understanding of Context

The term *context* is used in many different interpretations. In this thesis, we use Thüs et al.'s definition of *extrinsic* and *intrinsic context* [105]. Here, extrinsic refers to environmental characteristics and elements, such as the learner's current location, objects in the environment, and the current time of day. Intrinsic context elements are internal to the learner, including their prior knowledge and cognitive state. In particular, we are interested in everyday contexts and embedding (self-directed) learning into real-life settings.

### 2.1.2 Situated Cognition and Situated Learning

One of the core theories in context-based learning is *situated cognition* [10, 95]. Specifically, Brown et al. argue that learning is "a continuous life-long process resulting from acting in situations" [10]. For example, for learning a new word, seeing this word in an authentic context is essential for capturing the nuances of its meaning [10]. It is easier to grasp a concept when it is immediately experienced rather than described because understanding the description requires additional cognitive resources. Hence, the authors recommend that instructors enable *cognitive apprenticeships* where learners immerse in authentic activities and social interaction. Our work uses authentic contexts when learners take photographs to generate learning material, as in [P4.4]. Moreover, we simulate an authentic learning context when embedding learning into reading a book [P3.2, P3.1] or watching a movie [P3.3].

Situated cognition is also closely related to *situated learning* [60], which specifically stresses the role of authentic *social* contexts defined as *communities of practice*. Here, learning is situated in the sense that the context where the learning takes place and where the acquired knowledge is applied is the same. Although the learning experiences in our work are primarily individual rather than social, the dual role of context for learning and application is also reflected in the choice of everyday situations for our learning scenarios.

### 2.1.3 Context-Aware and Context-Adaptive Learning

Another emerging perspective on context in learning is context-aware and context-adaptive learning. Here, the learner's intrinsic and extrinsic context serves as a basis for adapting learning materials and elements of the learning experience [80, 105]. Much of the context awareness and adaptation research originates from technology-supported learning because technology is a key enabler of context-based adaptivity. Empirical studies show several benefits of context-adaptivity for learning. For example, Huang et al. [46] found that learners achieved higher recognition scores when target vocabulary was related to their location. Similarly, AR labels attached to real-world objects improved learners' vocabulary recall compared to traditional vocabulary flashcards [49]. Adaptation to past performance, i.e. a learner-related context factor, can also improve engagement [96] and test results [82].

The central approach in this thesis is adapting u-learning based on extrinsic (and partly intrinsic) learner contexts. For instance, triggering learning opportunities based on location [P2.2] considers extrinsic context characteristics. Conversely, resumption cues for mobile learning support learners in a state of disruption [P1.2].

### 2.1.4 Context Affordances

Besides providing an anchor for associations, context also influences learning situations [93, 105]. Context affordances are particularly relevant in ubiquitous learning because learning settings are not restrained in time and place, and the characteristics of a learning situation are not always known.

Generally speaking, a calm environment can facilitate a learner's ability to focus. In contrast, distractions such as push notifications received on a mobile device increase the probability of interruptions [121].

However, this does not mean that interruption-prone environments are not suitable for any type of learning; rather, the learning experience needs to be adapted to current learner needs. For example, a common practice in mobile learning is *microlearning*, where learning material is chunked into small bits that can be completed in short availability windows with little dependence on the location [47].

The context characteristics often inherently match specific types of learning content. For instance, when embedding learning into watching a movie, it makes sense to target vocabulary comprehension (as in [P3.3]). A short bus ride is probably best suited for brief recall practice, while longer focus times at home are a better setting for grasping novel, more complex concepts.

In this thesis, we address affordances in two main ways: by mitigating interruption effects in [P1.2] and by matching opportune moments and learning activities in [P2.2, P2.1, P3.2, P3.3]. For the remaining projects, we apply microlearning strategies.

### 2.1.5 Context-Dependent Memory

*Encoding specificity* states that memory retrieval is improved when the encoding context is the same as the retrieval context [108]. In other words, a memory is more likely to be recalled when external or internal cues present during memory encoding are also present during retrieval because contextual information is stored along with the target information [100]. For example, the famous scuba diving experiment by Godden and Baddeley [31] showed *context-dependent* *memory* effects in word recall. Specifically, participants memorised lists of words (1) on land and (2) underwater. They could recall more words during a subsequent recall test when the memorisation and recall settings were the same.

This also entails that too much focus on context-dependent information can limit learners' generalisation capabilities. Consequently, good instructional design might start off with a detailed context-based example before transitioning to formal representations of the same problem type; this is defined as *concreteness fading* [8, 116].

Context dependence may also arise in the learning experiences we investigate in this thesis. For example, if participants only add one image to study a word in [P4.4], this will not enable them to flexibly apply their knowledge in other contexts. We also discuss this in Section 7.4.

## 2.2 Motivation and Interest

Motivation is also key to learning. Why else would we willingly submit to laborious studies of irregular German verbs and repeated practice of a new piano piece?

Motivation is typically characterised as intrinsic or extrinsic [85, 86]. Intrinsic motivation is triggered by an activity itself, e.g. a learning task that learners find inherently engaging. Factors that promote extrinsic motivation include rewards and praise but also the perceived value in achieving a learning goal. Intrinsic motivation, in particular, is associated with performance benefits, although both types can foster learning [85].

The role of motivation in learning and factors that increase motivation have been studied from multiple perspectives. Here, we summarise self-determination theory, the connection between interest and motivation, and their implications for the design of context-aware learning experiences. Note that another common practice for increasing motivation in learning is gamification [56]. However, that is out of the scope of this thesis.

### 2.2.1 Self-Determination Theory

Self-determination theory (SDT) defines three innate needs that foster motivation: *autonomy*, *competence*, and *relatedness* [75, 86]. Autonomous learners take control of their actions, e.g. when choosing a learning activity they want to engage in. This promotes their sense of initiative and ownership. Competence is achieved by selecting material with an adequate level of difficulty in accordance with the learner's prior knowledge and individual pace. Relatedness means that learners feel connected to the (social) context, e.g. through a caring instructor. Satisfying these needs supports intrinsic motivation and persistent engagement in learning activities [75].

SDT was an important consideration for the interaction design in our learning experiences. For instance, we cater to the learner's autonomy by asking them whether now is a good time to learn in [P2.1] and by letting them choose their own photographs in [P4.4].

### 2.2.2 Interest

The second perspective takes a closer look at *interest* in its own right. Hidi and Renninger [39] explore interest as a "motivational variable", representing the readiness to engage and re-engage with learning content. They describe interest as a concept that combines affective and cognitive components and can be both situational and individual (internally driven). Both of these types foster cognitive performance and attention, amongst others. Moreover, individual interest positively influences persistence. Learners develop interest in four stages: triggered situational interest, maintained situational interest, emerging individual interest, and well-developed individual interest. Harackiewicz et al. [35] summarise instructional design strategies that cater to situational and individual interests. For example, learning material can be personalised to a learner's existing interests (e.g. matching a mathematics task description to a hobby). When learners take an active role in personalising tasks to their needs, this can increase ownership and strengthen connections.

The interest perspective is particularly relevant in our work because it manifests strong ties to the learner's environment and taps into their curiosity. For instance, in [P4.1] and [P4.4], several study participants said they would use our proposed apps to explore their environment.

## 2.3 Elements of Successful Learning Experiences

An optimally designed learning experience enables learners to achieve their learning goals efficiently and effectively. This section summarises the role of working memory, long-term memory, and cognitive load. Based on this background, I discuss guiding principles for designing the content and interaction in ubiquitous learning experiences with and without technology support.

### 2.3.1 Memory and Cognitive Load

During learning, information is processed in working memory, synthesised with existing knowledge from the long-term memory (LTM), and encoded in LTM [54]. Effective processing in working memory depends on the memory load, which is closely linked to the type of information that is processed. Baddeley [2, 3] differentiates information types processed in the *phonological loop* (verbal and auditory information) and *visuospatial sketchpad* (visual and spatial information). These are coordinated by a *central executive* function and supported through the *episodic buffer* with access to LTM. The phonological loop and visuospatial sketchpad can generally work in parallel, which means that auditory and visual processing can occur simultaneously. On the other hand, dealing with two sources within one component at once increases cognitive load. For example, hearing a sequence of numbers while looking at an image produces a lower load than hearing a sequence of numbers while reading a text.

Cognitive Load Theory (CLT) [102, 111] further explains that the success of a learning process depends on the *intrinsic*, *extraneous*, and *germane load* of the learning task. Intrinsic load refers to the complexity of the information processing. It correlates with the *element interactivity* of the learning task, i.e. the degree to which learning items can be studied in isolation or not. A learner's prior knowledge influences the intrinsic load of a task. Extraneous load is caused by the instructional design. It is high when learners need to keep information in working memory, e.g. when integrating information across spatially separated sources or processing redundant information from different sources. When learning systems are complex, or users are not familiar with them, this can also add to the extraneous load [44]. Finally, germane load arises from schema construction and automation and is productive for learning.

These types of load constitute the overall memory load. For successful learning, the overall load should not surpass the maximum memory capacity available. With practice, the required memory resources decrease. For example, as one learns to read, the process becomes more and more fluent and requires less focus on individual letters. Similarly, acquired cognitive schemata retrieved from LTM facilitate the processing within working memory. Good instructional design can reduce extraneous load and, thus, leave more resources available for the germane load.

While the working memory capacity has clear limits, LTM allows for practically infinite capacity [54]. In our context, we focus on the declarative component of LTM, which stores explicit and conscious memories [109]. Information in declarative memory can be semantic (concept-focused knowledge), episodic (personal experiences in time and space), or a combination [107]. Encoding is one of the factors that influence the retrieval experience. For example, when recalling a special gift we received, we may relive the moment in memory. Conversely, to apply Pythagoras's theorem in a math class, we do not need to remember the moment we learned about it. Nonetheless, storage is not always permanent. For example, we may forget memories when we do not access them for a while, and memories can also interfere with one another [88].

### 2.3.2 Dual-Coding Theory and Multimedia Learning

The cognitive principles outlined above define factors that foster or impede processing and recall in learning and, consequently, guidelines for designing learning material. One concept that is widely adopted in technology-supported learning is *multimedia learning* [67, 68], which builds on CLT, dual-coding theory (DCT), and the active processing hypothesis (see below).

DCT posits that encoding the same learned material as imagery and verbal information increases the probability of recall [19]; the multimedia principle transfers this to concrete multimedia settings and states that combining words and pictures is better for learning than using words alone. For example, studies in a language learning context have shown benefits of combining texts with images for vocabulary acquisition [17] and audio with transcripts or imagery for listening comprehension and vocabulary acquisition [51]. However, considering CLT, it is important that the different modalities do not interfere with each other (redundancy principle [67]).

The multimedia learning principle also guided the design of the different types of learning material in our projects. For example, the object-based learning material in [P4.1, P4.4, P4.2] combines visual representations of objects with matching captions to improve recall.

### 2.3.3 Further Learning Strategies

How new information is processed and mentally organised is also a determining factor for long-term retention. Notably, recall improves when learners actively engage with the learning material. In this context, the term *desirable difficulties* denotes practices with deep levels of processing [6]. For example, tests, where learners have to produce answers rather than simply recognise them, are more beneficial for learning [83]. Relatedly, it helps when learners employ *active processing* strategies, i.e. when they successfully focus attention on relevant information, mentally organise it into coherent structures, and connect it to prior knowledge [68]. *Spaced repetition*, i.e. revisiting information after increasing intervals [13, 53], and *interleaved practice*, i.e. alternating between topics rather than blocking them one after the other [104], also both foster recall. While not the major focus of this thesis, we considered these strategies in the design of our interventions. For example, adding verbs to a noun in [P4.3] supports active processing, while the tests in [P4.4] encourage spaced repetition.

## 2.4 Technology Support for Connecting Learning to Learner Contexts

Technology is a key enabler for connecting learning to the learner's context and, thus, for leveraging the benefits of context for learning without increasing the load on instructors. Specifically, sensing and modelling technologies take into account extrinsic and intrinsic context factors, such as a learner's prior knowledge, their interests, and their current state of mind [62, 80, 99]. Targeted use of personalised and context-aware technology can improve learning performance, need satisfaction, and intrinsic motivation [62, 122].

Past work has also analysed the unique affordances of different context-aware and ubiquitous technologies for learning. Notably, mobile devices such as smartphones can use embedded sensors to adapt learning experiences to individual environment characteristics—at home and on the move [93]. Augmented Reality fosters situated learning by directly linking learners and the learning content embedded into an authentic environment [24, 87, 118]. Below, we summarise past work on context-aware adaptation for content and learning situations.

### 2.4.1 Context-Aware Content Personalisation

Context-aware content personalisation relies on scalable methods for selecting, adapting, and authoring learning materials. Past work has primarily explored approaches that sense learner states or physical context, including the location and elements present in the learner's surroundings (e.g. objects, texts, sounds).

Learner states include factors such as prior knowledge and current mental capacity. For example, the intelligent tutoring system Cognitive Tutor derives a knowledge model from learner behaviour (e.g. error rates and response time) to recommend knowledge components to study [82]. Behaviour tracking is also used for increasing or reducing scaffolding, e.g. adaptive hints in educational games [23] or providing explanations based on test performance [30]. Researchers also envision employing physiological sensing, e.g., EEG, to detect if learners are familiar with given vocabulary items [92].

Sensor-based approaches often use location detection or object tagging. For example, location-relevant vocabulary can be retrieved using GPS data combined with location classification (café, train station, park etc.) [26, 37]. Specifically, Hautasaari et al. [37] extracted keywords from Wikipedia articles related to the categories of street map entries, while Edge et al. [26] prepared vocabulary lists related to Foursquare location tags. Another project used RFID tags to determine what objects a learner was interacting with and suggested foreign vocabulary accordingly [4]. Recently, purely image-based information has also been used to detect objects of interest for language learning [36, 112]. With the aid of generative models, the reverse process is also possible: creating images that represent learning items, e.g. radiology images for diagnosis training [28].

Content generation from media can exploit the fact that learners already consume media in their everyday lives. Notably, Lungu et al. [65] automatically added manipulated websites to add translations, pronunciation hints, and vocabulary exercises, and Trusty and Truong [106] automatically replaced first-language words with their target-language equivalent. Meurers et al. [70] turned texts on target-language websites into grammar exercises by omitting articles, prepositions, etc. Natural language processing (NLP) can also be used to generate comprehension and grammar questions for foreign-language texts [16]. Applying NLP to Wikipedia articles, Wu et al. [120] further proposed a system that enables users to retrieve examples of commonly used word combinations related to a given topic. Moreover, video captions and subtitles enable viewers to learn vocabulary in (simulated) authentic contexts [110].

All these solutions allow learners to choose context elements and media they personally find interesting, potentially increasing their motivation to study. They vary in their degree of automation. Some require preprocessing, e.g. for vocabulary lists as in [26, 106]. Others adapt to user input, e.g. learner-selected websites and task types in [70]. And some propose fully automated sensing and presentation, e.g. location triggers combined with automated vocabulary extraction [37].

This thesis focuses on approaches with simple user input to balance flexibility, quality, and relevance.

### 2.4.2 Context-Aware Personalisation of Opportune Learning Situations

The context-aware personalisation of learning moments is largely driven by the detection of user activity and estimation of availability windows. For example, Dingler et al. [21] aimed to present vocabulary exercises when smartphone interaction suggested that a learner was bored. Cai et al. [12] proposed a set of potential moments like waiting for the elevator or a chat response to present short learning sessions that match personal activity patterns. Outside the learning domain, Kang et al. [52] sent notifications in detected idle moments, such as walking while listening to music and right after phone calls.

These techniques all aim to capture moments where learners are available. However, learners also need to be willing to engage with a learning task; this is a main motivation for our work on learning triggers in [P2.1].

Another important component of making learning situations context-aware is to present learning content differently depending on context affordances (cf. Section 2.1.4). Technology can support learners by adapting the presentation of learning contents to context characteristics such as the current location, available time, and the learner's level of focus [74, 105]. This thesis specifically addresses context adaptations for task resumption in [P1.2].

## 2.5 Domain Choices

In the scope of this thesis, we had to prioritise focus domains as the common basis for our research contributions: within the space of context-aware ubiquitous learning, we emphasise self-directed language learning. Here, we summarise the rationale of our decisions and explain how they relate to the larger context of learning.

### 2.5.1 Self-Directed Learning

We focus on self-directed scenarios because these can accommodate individual connections to the real world. Merriam [69] defines self-directed learning (SDL) as "Learning that is widespread, that occurs as part of adults' everyday life, and that is systematic yet does not depend on an instructor or a classroom". Hence, the learners themselves primarily drive learning, and it is up to them to decide what they want to learn and when. This gives learners freedom and autonomy. However, it also means they must make decisions and are responsible for their actions. Therefore, self-directed learners require effective self-regulation and intrinsic motivation to actively pursue long-term learning goals [18, 64, 75].

Motivation was a key component in several of our studies, and variations of learner engagement in our SDL settings helped us gain insights into the effects that contextualisation had on learner motivation.

### 2.5.2 Ubiquitous Learning, Mobile Learning, and Microlearning

SDL is often supported by mobile and ubiquitous technology, such as smartphones and AR headsets. These devices enable ubiquitous learning, i.e. learning that can occur anywhere and anytime [93]. Given our context-aware scenario, we further classify our learning approach as *context-aware* ubiquitous learning. Hwang et al. define this as "u-learning that employs mobile devices, wireless communications and sensor technologies in learning activities" [48]. The sensing "allows the learning system to better understand the learner's behavior and the timely environmental parameters in the real world". In other words, learning experiences are adapted based on the context factors.

Learning sessions on mobile and ubiquitous devices are commonly realised through microlearning (cf. Section 2.1.4). We also employ microlearning techniques in this thesis, primarily on smartphones (including smartphone-based handheld AR) and e-readers. We opted for these devices because they are widely available and because users are already familiar with them, minimising the extraneous load caused by getting used to novel systems.

### 2.5.3 Language Learning as a Petri Dish

The work presented in this thesis relies on language learning as an exemplary use case. Besides providing a consistent working domain, there are several reasons why we deem language learning a well-suited representative of learning.

First, language learning has many facets: it requires rote learning and conceptual understanding, analytic skills, and the creative recombination of what has been learned. Thus, a holistic language learning experience has passive (primarily reading and listening) and active components (writing and speaking), with a focus on either meaning or linguistic patterns [73]. Second, language learning has a clear connection to the real world: we can describe the world around us with language, and the associations of words and imagery (e.g. concrete and mental pictures of our environment) support recall [77]. Third, the widespread availability and adoption of mobile language learning apps mean that we can position our work on top of a well-researched and well-established foundation. It also means that we address a topic that is interesting to millions of people—Duolingo, for example, counted 49.5m active users in June 2022[1]. Finally, there are various reasons why people want to learn a language. This reflects individual needs, from a tourist who wants to develop speaking skills to place orders at a restaurant to a lawyer who needs to read foreign-language policies with attention to detail. These individual differences are exactly what we aim to address with our personalisation and contextualisation approaches.

In sum, language learning is our Petri dish; it is a representative use case based on which generalisations to other learning domains can be motivated.

[1] https://investors.duolingo.com/news-releases/news-release-details/duolingo-announces-51-bookings-growth-and-accelerating-user

# 3 Research Challenges

In the previous section, we discussed the benefits of connecting (language) learning to learners' real-life contexts. However, in current learning practices, several factors disconnect the process of learning from a learner's everyday life [62], both in terms of *learning situations* and *learning contents*.

With respect to learning situations outside of classrooms, the disconnection from the real world shows in high dropout rates [29, 55]. For example, García Botero et al. [29] tracked Duolingo learners over a year and found that while 87 participants were active in the first month, only 14 still used Duolingo 12 months later. And even though many learning apps send push notifications as a reminder to keep learning, these are often triggered at a predefined time without considering the learner's current context (e.g. Babbel's scheduled reminders[1]).

Regarding learning content, curricula are often predefined (e.g. Duolingo learning paths [72]), meaning learners cannot choose materials based on their interests. Reasons for this include the effort required for context-aware personalisation [116] but also the challenges in identifying opportune moments, learner interests, and prior knowledge without creating additional burdens for learners and instructors [1, 117]. In sum, the role of technology in learning is often that of a non-contextual *reminder* or *content presenter*.

Current-day technology, such as mobile devices, enables the contextualisation of learning. In other words, technology acts as a *mediator* between the learner and their environment and context by creating and adapting learning situations and contents. This thesis focuses on the *learner experience* of such context-aware learning experiences. Following the domain specifications defined in Section 2.5, it addresses factors such as user experience, engagement, and interaction patterns with ubiquitous language learning technology in the following two overarching research areas (see also Figure 3.1):

> **Research Area 1:** Technology for ubiquitous learning ***in*** learners' everyday contexts, i.e. technology that senses learner contexts and triggers learning situations.
>
> **Research Area 2:** Technology for ubiquitous learning ***from*** learners' everyday contexts, i.e. technology that adapts and generates context-aware learning material.

The remainder of this section outlines the research questions we addressed in these areas in more detail and motivates the main lines of research within these domains.

## 3.1 Learning *In* Everyday Contexts

In theory, mobile learning apps incorporating microlearning and spaced repetition promise effective learning with minimal time investment, everywhere and at any time. However, the high drop-out rates mentioned earlier indicate the limits of this promise. So what are the specific factors that disconnect mobile learners'[2] study habits from their everyday contexts and routines? To understand this, we first need to look at learning patterns in everyday life. This

[1] https://support.babbel.com/hc/en-us/articles/360037499092-How-to-Use-Learning-Reminders

[2] i.e. learners studying with mobile learning apps

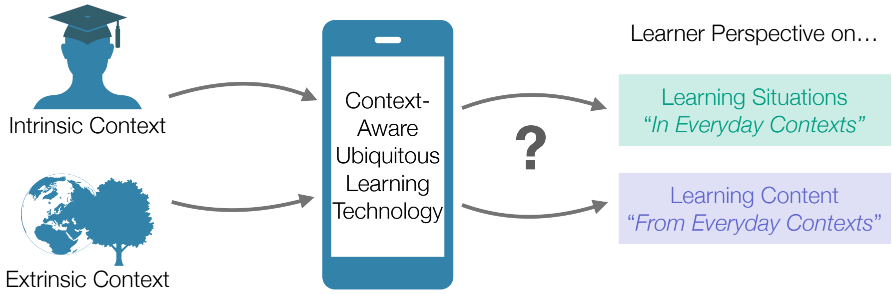


**Figure 3.1 How can we design context-aware ubiquitous learning technology that optimises the learner experience in terms of learning situations and learning content?**

includes learning situations, session characteristics, and context-dependent requirements (e.g. adaptations to interruptions). We approach this with the following research question:

> **RQ 1:** When, where, and how do mobile learners study in everyday contexts?

The insights gained in addressing RQ 1 inform opportunities for connecting learning to their context by triggering learning activities accordingly. This does not only concern learner availability but also moments where they are willing to engage in a learning activity. Especially the latter also requires matching learner context with learning modalities for a positive learner experience. For example, pronunciation practice is better suited for learning at home than on public transport. Therefore, RQ 2 addresses opportune moments for learning situations and notifying learners:

> **RQ 2:** How can we link opportune learning moments with context-aware learning triggers?

## 3.2 Learning *From* Everyday Contexts

So far, we have considered context awareness with respect to learning situations. In the second research domain, we turn to learning materials instead. Here, we investigate how context can serve as a basis for adapting or creating learning material that is interesting and relevant to learners in order to increase their motivation and engagement [39].

So how do we know what learners are interested in and from which context elements we can derive personally relevant learning material? Past work on content adaptation has often relied on modelling a learner's current knowledge state [80]. This works well when learning happens within an isolated system without external influences. However, current-day language learners often include media and online resources in their learning process [32], e.g. when they watch Khan Academy videos on top of their calculus class or when they form a language tandem with a native speaker.

Therefore, we focus on interactive approaches instead. Here, we rely on learner activity to derive potential points of interest. Concretely, we investigate the learner perspective on passive and active starting points for contextualising learning materials in language learning. For the passive approach, we focus on the augmentation of learner activities, i.e. passively embedding learning into activities that learners already perform. As described in Section 2.4.1, past work has proposed activities such as reading and audiovisual media as potential learning scenarios. However, little is known about the learners' needs and preferences with respect to the balance between these activities and learning: how much support is needed and how should it be designed to enable learning without annoying learners? We address this with the following research question:

> **RQ 3:** What are learner needs and preferences in the augmentation of everyday activities for enabling learning?

The passive approach is easy to embed into everyday life. However, it only covers a part of the space of opportunity for creating learning material from context. Consequently, we explore if and how we can cater to specific learner interests by actively *generating* new learning materials from their contexts. In Section 2.1, we argued that context-aware personalisation can benefit engagement and learning performance, and we listed several technologies that enable such personalisation. However, many open questions remain, such as strategies for successful interaction design, how to create versatile, high-quality learning material, and the learners' opinions on generated learning material. We address these aspects in RQ 4:

> **RQ 4:** What are learner needs and preferences in the auto-generation of personally relevant learning material from learner contexts?

# 4 Research Approach and Methods

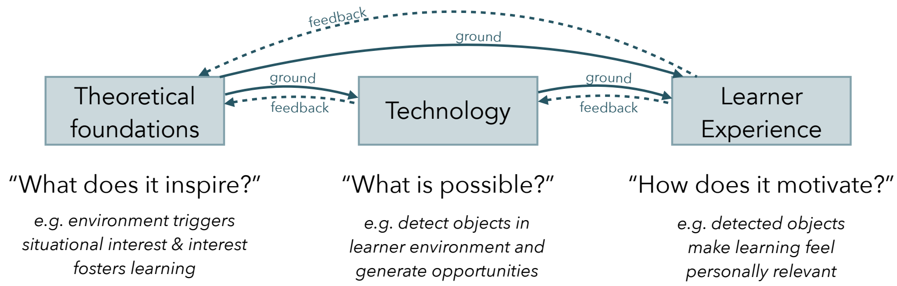


**Figure 4.1 Research approach followed in this thesis.**

In this section, we first explain how we situate our work at the intersection of computer science and technology, and how this relates to research paradigms in HCI. The second part continues with a discussion of our concrete research methods. It describes our rationale for choosing development and evaluation methods applied in the different projects and includes a retrospective assessment of the benefits and challenges that these methods entail.

## 4.1 Research Paradigms

Situated in human-computer interaction (HCI), this work synthesises approaches and findings from computer science, psychology, and cognitive science to derive insights into the learner experience. Figure 4.1 gives an overview of the three pillars *theoretical foundations*, *technology*, and *learner experience* and their interconnections in my research approach.

Psychology and cognitive science provide the theoretical foundations and inspiration. In particular, the work relies on findings in the domains of learning psychology, memory, cognitive load, and situatedness in learner contexts but also user experience and behavioural intention. These principles inform and inspire the technology perspective and learner experience.

These foundations guide the implementation work in the technology domain. For instance, the theory of multimedia learning (cf. Section 2.3.2) inspired combining verbal and imagery representations of learning material in [P4.3, P4.4].

In the learner experience domain, theoretical foundations motivate the choice of interaction concepts and presentation. For example, personal relevance was the basis for using personal photographs in [P4.4].

Our contributions are mainly situated in the technology and learner experience domain. However, they also inform further research in cognitive science and psychology, as illustrated by the *feedback* link from technology and learner experience back to the theoretical foundations. For instance, our findings on the perceived quality of auto-generated learning context-aware material in [P4.4] inspire additional investigation of perceived ownership and expectancy violations in human-AI collaboration.

In terms of Wobbrock and Kientz's classification of research contributions in human-computer interaction [119], the publications included in this thesis contribute novel artefacts (e.g. headphone triggers for audio-based learning [P2.1] and an AR system for grammar learning [P4.1]), empirical studies (e.g. on the reading flow in e-readers with grammar support [P3.2] and the learner assessment of auto-generated flashcards [P4.4]). The thesis itself further expands theory with our overarching framework for the roles of technology in context-aware learning (cf. Section 6.2). Through this combination of approaches, this work expands our practical knowledge of context-aware technologies, their implication for learning in practice, and derives future research challenges.

## 4.2 Design Processes

Learners are the key stakeholders of this thesis. Therefore, the research methods strongly focus on their perspective; they are involved in the planning, development, and evaluation stages. Depending on the specific research goals and research questions, we built artefacts based on focus groups and user surveys and relied on findings from past work.

***Artefacts*** were typically self-developed or adapted mobile apps that I and the students I supervised implemented. As smartphone apps, they matched common ubiquitous learning practices and served as high-quality prototypes for realistic user evaluations. The mobile apps followed common user experience patterns (e.g. Material Design guidelines), and this also resulted in high usability scores reported in studies (e.g. SUS scores [9] typically ranging in the 80s-90s). Moreover, thanks to the custom implementation, we could easily add logging to track target measures, e.g. for user engagement. In [P4.4], we embedded surveys in the app for a seamless evaluation experience. We typically deployed apps via the Play Store, completing the full verification process. Thus, we could run remote studies with minimal supervision. For earlier conceptual stages, we also developed click prototypes that allowed for quick adjustments but still had sufficient functionality for lab studies, e.g. in [P3.2, P1.2].

***Focus groups*** were used to identify learner needs before and during the design process. For example, in [P3.1], we asked potential users what augmentations they would add to an e-reader interface that supports grammar learning. In addition, we asked teachers what grammar constructs their students typically struggle with and how they could be integrated into an e-reader interface. The statements collected in the focus groups were essential for the subsequent design of our e-reader interface. Similarly, in [P1.2], focus group participants applied the Lotus blossom method [40] to generate ideas for task resumption cues.

***Formative surveys*** were applied to gain early insights from a larger sample and when less detail was required. For example, in [P3.3], we deployed a survey to understand caption usage in everyday life, including usage situations and preferred caption settings. For [P2.1], we asked respondents what types of activity reminders they typically used.

***Past work and related literature*** were also essential building blocks for our concepts: in-depth analyses of related concepts were important for identifying research gaps and for design recommendations. We also used existing work as a starting point for our follow-up work. For example, an analysis of prior work in the context of [P4.1] showed that past projects had almost exclusively focused on learning concrete nouns. Grammar had not been addressed, despite being equally relevant in language learning [38, 73]. Design guidelines were important for details such as push notifications: based on [78], we triggered daily push notifications in [P4.4]. In [P3.3], we devised caption variants that extended designs proposed in prior work. For example, we added time synchronisation to captions with keyword highlights [66].

Through the combination of different methods, we were able to implement concepts at varying levels of granularity and fidelity as required for individual projects. Moreover, involving potential users and analysing past work was essential for validity and generalisability.

## 4.3 Evaluation Methods

The projects conducted in the scope of this thesis required a wide array of summative evaluation techniques matched to the different use cases. We collected quantitative data (e.g. interaction counts derived from logs) and complemented these with qualitative data (e.g. participant statements on problems they encountered) to achieve a fine-grained view of the users' experience. This enabled us to observe trends, identify reasons why these trends exist, and derive promising directions for future work.

We evaluated the quantitative data with statistical methods such as t-tests, ANOVAs, and regression models; all of these are typical methods applied in HCI research [61]. In some cases (e.g. [P2.1, P4.1]), we also apply Bayesian tests that are particularly well suited for exploratory analyses because they allow a direct comparison of the likelihood of the null and alternative hypothesis [57, 114]. Below, we characterise the situations where we opted for surveys, lab studies, in-situ studies, and interviews.

***Lab studies*** were essential for consistent setups that enabled a focused comparison of design concepts or interventions with a clear set of dependent variables. For example, for [P4.1], it was necessary that every participant in the experimental group could interact with the same objects and that participants in the control group also received equivalent learning materials. Moreover, we added delayed online post-tests to study learning to control for short-term memory effects [25, 67].

Similarly, the reading studies in [P3.1] and [P3.2] were held in lab settings to control for environmental effects and clearly focus on the user experience and reading flow, respectively.

***In-situ studies*** or field studies were the go-to method for (1) assessing real-world behaviour and (2) evaluating the practical use of novel apps for learning embedded in everyday life and after repeated use. We typically enhanced the field studies with pre-test and post-test surveys. Notably, in [P1.1], we evaluated typical mobile learning sessions and interruptions in self-directed learning. To capture detail beyond the mobile devices' sensor data, we integrated experience sampling [5]. With the second approach, we studied the everyday application of our novel learning interventions in [P2.1, P4.3, P4.4, P3.3]. Typically, we compared the interaction with a control group, for example, in terms of time spent learning, the correctness rate in recall exercises, and the learner-triggered content generation. The studies for [P4.4, P3.3] were conducted via the online recruitment platform Prolific[1]. This enabled us to target specific user groups, such as native Spanish speakers, beyond our university circles.

***Summative surveys*** were typically deployed in conjunction with the other research methods. Specifically, we used them for established questionnaires such as the (Short) User Experience Questionnaire [94] and System Usability Scale [9] as well as to collect qualitative feedback in remote studies.

***Interviews*** served a similar purpose as surveys. In [P4.3], we chose an interview format for post-study assessments because the study participants were children and deemed verbal communication easier. It also meant we could ask follow-up questions for clarification and more

[1] https://prolific.co

details. On the other hand, recruiting participants for interviews was often difficult. For instance, only two of the twelve participants of a pilot study conducted in the scope of [P4.4] were willing to participate in a follow-up interview, despite additional compensation.

## 4.4 Method Reflections and Limitations

Working in the (language) learning domain is rewarding because it has real-life relevance for many people and because we can observe immediate successes achieved thanks to our work. However, it also poses several challenges for the design and running evaluations.

In terms of design, we took great care to implement working systems that learners could use independently, often on their own devices, and that integrated state-of-the-art technologies for Augmented Reality, computer vision, or natural language processing. However, the learning experiences we developed typically focused on a few specific aspects of interest, e.g. creating flashcards with object detection for one specific grammatical construct [P4.4]. Moreover, the participants involved in our design processes were primarily young adults from Germany who already had some experience with learning technologies. Thus, our systems can provide a scientific basis for further developments of full-fledged commercial systems but do not reach the same standards with regard to long-term efficiency, versatility, and performance.

In terms of evaluation, the most informative studies were the in-situ studies reported in [P2.1, P4.3, P4.4, P1.1], where participants repeatedly used our apps at home. In-situ studies provide high real-life validity, but they also introduce a number of potential confounds [84]. For example, we encountered issues with different Android versions and, in some studies, experienced high drop-out rates. A major challenge was finding a good balance between resources and the generalisability of results. Specifically, when we ran studies that targeted conceptual learning, we often had to apply between-group designs to avoid the impact of learning effects. This resulted in lower statistical power in comparison to within-subject designs. Using Bayesian evaluation methods was helpful here to quantify evidence. In addition, the study periods of one session (plus delayed post-tests) up to four weeks can only provide limited insights into long-term engagement and learning. This is a common issue in studies of technology-supported learning [11, 62]. Moreover, with our HCI-focused projects, we primarily assessed user perspectives such as subjective experience and quantified interaction. This perspective is crucial for long-term adoption [113], but it also means that we cannot make general claims on learning benefits. However, measuring a multi-faceted construct such as learning in everyday contexts is actually a challenge in itself [97]: In the absence of a standard curriculum, we cannot simply administer pre-tests and post-tests for a fixed list of learning items.

Ethics and privacy were also very important aspects of our work. All experiments respected the Declaration of Helsinki; after the establishment of the faculty's ethics committee, we also obtained an ethics confirmation before carrying out experiments involving people. We informed participants (for [P4.3] also their guardians) about the study procedure and potential risks and only proceeded with their consent. We also took care to preserve user privacy in the study procedures and the design of the research probes. For example, in [P4.4], users could opt out of sharing a photo with us when they added it to their list of flashcards, and we kept required app permissions to a minimum by not using external storage and camera access.

# 5 Publications

This chapter outlines the publications along the four research questions introduced in Chapter 3. For each publication, I provide a brief summary and position the work within the larger scope of the research domain. A synthesis of the contributions in light of the research questions follows in Section 6.1. Chapter 8 provides a collaboration statement for all included publications.

## 5.1 Mobile Learning Situations in Everyday Contexts

*RQ 1: When, where, and how do mobile learners study in everyday contexts?*

The settings in mobile learning are more diverse and dynamic than in traditional classroom learning and also require different learning strategies. For example, classroom learning usually means that a fixed and extended time is reserved for learning activities. In contrast, opportunity windows in ubiquitous learning include comparatively short moments such as bus rides and are often prone to interruptions (cf. Section 2.1.4).

In this space, we employed technology as a sensor for assessing learning habits in everyday contexts. Building on this, we investigated how learning can take place despite the interruptions, by supporting task resumption after an interruption has been detected.

### 5.1.1 Assessing Learning Habits

In [P1.1], our goal was to understand learning habits and identify requirements for tailoring learning experiences to context factors. To this end, we studied the everyday-life learning behaviour of learners using mobile learning apps for ubiquitous learning, including the interruptions they experience. Specifically, we logged learning sessions and checked what events occurred just before learners terminated a learning session (e.g. if they received push notifications on their device). We augmented the log data with experience sampling questionnaires to characterise the learning session (e.g. location, company) and the reasons for ending a session (i.e. self-interruptions, device-internal interruptions, and external interruptions depending on the interruption source [90]). We found that learning sessions are spread out across the day, with activity peaks in the morning, around lunchtime, and in the evening. The sessions are typically short ($MD \approx 8$ minutes in our study) and frequently interrupted (almost 40% of logged sessions). Moreover, interruptions often cause unplanned session termination.

This fragmentation nature of mobile learning underscores the need for adapting learning for short activity bursts. As mentioned in Section 2.5.2, many mobile learning apps address this by implementing microlearning strategies, where content is chunked into small independent units. This works well for use cases such as spaced repetition in vocabulary learning. However, the microlearning design makes it challenging to convey larger-scale concepts with *high element interactivity* [101] that require interconnection between the learning elements, e.g. learning about relativity theory (cf. Section 2.3.1). Nonetheless, we see at least two possible approaches for including learning concepts with higher element interactivity. (1) Context factors such as the available time and current noise level can be queried to adapt instruction design [74], see also Section 2.1.4. (2) Learning experiences can be designed to enable learning across interruptions, e.g. by mitigating the effect of interruptions, which we discuss below.

Fiona Draxler, Christina Schneegass, Jonas Safranek, and Heinrich Hussmann. 2021. Why did you stop? - Investigating origins and effects of interruptions during mobile language learning. In *Mensch und Computer 2021*. MuC '21: Mensch und Computer 2021. ACM, Ingolstadt Germany, (Sept. 5, 2021), 21–33. ISBN: 978-1-4503-8645-6. DOI: 10.1145/3473856.3473881

### 5.1.2 Learning Despite Interruptions

Interruptions will continue to occur in ubiquitous learning. In some situations, they may be avoided. This is widely discussed in digital wellbeing research, e.g. in the context of grouping and postponing push notifications [33] and supporting self-reflection [7].

Yet, avoiding is not always possible. For example, we will still pick up the phone when an important call comes in or stop an activity when we get off the bus. Therefore, in the context of [P1.2], we focused on mitigating the effects of an interruption instead. Concretely, we investigated task resumption support in mobile learning. We asked learners what they thought would help them regain context after an interruption. For example, they suggested a summary of previous activities, comparable to plot summaries of TV shows, and a meditation exercise to regain focus. The idea is that when a learning system senses that an interruption has occurred, such task resumption cues could restore the working memory context when learners return to the learning activity.

In follow-up work, we further analysed how task resumption cues from other domains could be transferred to mobile-learning scenarios [90] and we implemented and evaluated several variants [91]. Findings from these studies are summarised in Christina Schneegass's doctoral thesis [89].

Fiona Draxler, Christina Schneegass, and Evangelos Niforatos. 2019. Designing for task resumption support in mobile learning. In *Proceedings of the 21st International Conference on Human-Computer Interaction with Mobile Devices and Services*. MobileHCI '19: 21st International Conference on Human-Computer Interaction with Mobile Devices and Services. ACM, Taipei Taiwan, (Oct. 2019), 1–6. ISBN: 978-1-4503-6825-4. DOI: 10.1145/3338286.3344394

## 5.2 Designing Triggers for Opportune Learning Moments

*RQ 2: How can we link opportune learning moments with context-aware learning triggers?*

Even though many types of spare moments can be used for ubiquitous learning, these opportunities are easily missed; they pass by unnoticed or catch learners in unwelcome moments. Moreover, learning experiences should be matched to the affordances of potential learning situations to be effective. In this domain, we explored the characteristics of different learning triggers and their match to learning situations.

### 5.2.1 Triggers for Availability and Willingness to Engage

In [P2.1], we deployed a survey on commonly applied reminder strategies. We designed two exemplary types of learning triggers, analysed their effects in everyday-live settings, and used them as a basis for discussing activity-matched triggers and habits.

The survey showed that people often relied on their memory and handwritten notes to remind themselves to engage in a task. They were less likely to employ digital methods. For example, only half of them used scheduled or location-based reminders more often than a few times a year. This served as a motivation to explore the potential of digital activity triggers. The first learning trigger utilised the learners' calendar entries. We sent push notifications in gaps between events, which represented potential availability. However, this turned out to be insufficient in practice. For once, not everyone consistently organises their calendar and registers all events. In addition, being available does not always entail motivation to engage in a learning activity. Hence, it is questionable if reading privacy-relevant data such as calendar entries is justified given the low impact on engagement. The second learning trigger, therefore, was clearly linked to an event that signified readiness: whenever learners plugged in their headphones, we asked them if they were available for an audio-based learning session. This method achieved very high compliance rates of approximately 87%, suggesting that interaction-based triggers that are well-matched to learning activities are a promising path to follow.

This project shows an example of how connecting learning situations to everyday settings creates a window of opportunity where the willingness to engage coincides with availability. Overall, it indicates that learners should be supported in identifying the individual links between their context and environment and establishing long-lasting learning habits.

> Fiona Draxler, Julia Maria Brenner, Manuela Eska, Albrecht Schmidt, and Lewis L Chuang. 2022. Agenda- and activity-based triggers for microlearning. In *27th International Conference on Intelligent User Interfaces*. IUI '22: 27th International Conference on Intelligent User Interfaces. ACM, Helsinki Finland, (Mar. 22, 2022), 620–632. ISBN: 978-1-4503-9144-3. DOI: 10.1145/3490099.3511133

### 5.2.2 Linking Locations and Learning Contents

With [P2.2], we additionally explored an extension of the opportunity space by linking locations with learning contents. We developed a mobile app that detects RFID tags placed at opportune locations, e.g. at the coffee machine, and triggers associated learning quizzes. The project was inspired by the common practice to attach sticky notes to objects around one's house, e.g. to revise for an upcoming exam while brushing one's teeth. The app was not tested with learners, but it follows strategies of the method of loci, a mnemonic practice where knowledge is linked to physical locations [81]. The source code is available on GitHub[1].

> Fiona Draxler. 2022. Using wearables to optimize learning at home. In *Sense, Feel, Design*. Vol. 13198. Carmelo Ardito, Rosa Lanzilotti, Alessio Malizia, Marta Larusdottir, Lucio Davide Spano, José Campos, Morten Hertzum, Tilo Mentler, José Abdelnour Nocera, Lara Piccolo, Stefan Sauer, and Gerrit van der Veer, editors. Series Title: Lecture Notes in Computer Science. Springer International Publishing, Cham, 474–480. ISBN: 978-3-030-98388-8. DOI: 10.1007/978-3-030-98388-8_42

## 5.3 Augmenting Everyday Experiences

*RQ 3: What are learner needs and preferences in the augmentation of everyday activities for enabling learning?*

[1] https://github.com/fionade/tagged-revision

Above, we focused on learning activities that are largely independent from the current context. However, activities themselves can also be transformed into learning opportunities. Notably, we studied the design of learning support interfaces for foreign-language reading and captioned audiovisual media as examples of enjoyable activities that are enhanced for a purpose. The combination of entertainment with learning promises to increase motivation, and the reading and viewing content contextualises the learning material by immersing learners in the plot.

### 5.3.1 Augmenting Reading Interfaces

[P3.1] and [P3.2] investigate facets of grammar support in e-reader interfaces: the former focuses on design approaches while the latter investigates effects on the reading flow. Pop-up dictionaries in e-readers are already common practice. These dictionaries can support vocabulary learning in everyday life, but they are limited in terms of interactivity and scope. With our projects, we expanded e-reader interfaces to provide grammar support and studied the learner perspective on different visualisation and interaction methods.

In [P3.1], we assessed the user experience achieved with e-reader interfaces for grammar learning with different degrees of information load (explicitness). We conducted two focus groups, one with teachers and one with HCI students and potential learners. The teachers provided insights into typical issues that, in this case, German learners of English encounter and what methods they consider suitable for explaining grammar concepts. The HCI students and learners contributed design ideas for grammar visualisations and interaction patterns. For example, they suggested colour-coding grammatical structures and rule explanations shown as pop-ups or between lines. Based on the focus groups and an analysis of prior work, we designed four reading interfaces explaining the use of adverbs and adjectives: *Highlights* marked adverbial constructs and adjectives in different colours. Tapping highlighted words revealed arrows to illustrate what part of the sentence an adverb or adjective referred to. *Above* showed the words "Adjective" and "Adverb" above words of that type and showed short explanation boxes at the bottom of the page. *Footnotes* was very similar but used coloured footnote markers instead. Finally, *Window* showed case-specific explanations as a small pop-up on demand. In all designs, users could open large overlays explaining the grammar rules in detail.

Our lab study with 16 participants showed that case-specific explanations were particularly helpful. Readers preferred subtle annotations for a focus on reading flow (i.e. for extensive reading [73]) but could imagine more details for a learning focus (i.e. for intensive reading). Support elements should not override established functions of text markers; this was the case with footnotes, which were considered distracting. Overall, we showed that exploring interactive e-reader interfaces is a promising route to follow.

> Fiona Draxler, Christina Schneegass, Nicole Lippner, and Albrecht Schmidt. 2019. Exploring visualizations for digital reading augmentation to support grammar learning. In *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia - MUM '19*. the 18th International Conference. ACM Press, Pisa, Italy, 1–11. ISBN: 978-1-4503-7624-2. DOI: 10.1145/3365610.3365623

The different preferences for extensive and intensive reading that became apparent in the user study in [P3.1] motivated us to study the trade-off between information load and reading flow. This is relevant because if interruptions are perceived as too distracting, the enjoyment may suffer [20]. Consequently, learners may be less willing to incorporate learning into an everyday activity such as reading. Therefore, in [P3.2], we expand the work on grammar support in e-readers with a dedicated study on perceived reading flow. To this end, we employed a similar study set-up as in [P3.1]. Building on the preferred designs from the previous study, we implemented four design concepts of different levels of support. All designs included a dedicated *translation mode*, providing on-demand translations. *Level 0* only had the translation mode and represented the state of the art of current e-readers. All other levels also included a *grammar mode* for English past tenses. Specifically, in the grammar mode of *Level 1*, all past tense verbs and their modifiers were highlighted. *Level 2* additionally provided pop-ups that showed case-specific information for words a reader tapped on. *Level 3* introduced large overlays with more detailed information on the tenses.

Our 24 study participants then read parts of an Hercule Poirot detective story with each of the four designs. They reported on their reading flow and how usable and useful they found the designs. Unsurprisingly, reading flow tended to decrease with the information load while the perceived usefulness increased. Usability was best for Levels 0 and 2. Clearly, the overlay in Level 3 was too disruptive because participants could not keep their eyes on their reading position.

Taken together, this indicates that readers can maintain reading flow with annotations in the text as long as they are not too overwhelming. Again, how much information they can or want to process depends on an intensive or extensive reading focus. Therefore, adaptivity is key: readers should be able to request and hide the support they currently need with simple interaction patterns that have minimal impact on the extraneous load.

Fiona Draxler, Viktoriia Rakytianska, and Albrecht Schmidt. 2022. Maintaining reading flow in e-readers with interactive grammar augmentations for language learning. In *Proceedings of the 21st International Conference on Mobile and Ubiquitous Multimedia*. MUM 2022: 21th International Conference on Mobile and Ubiquitous Multimedia. ACM, Lisbon Portugal, (Nov. 27, 2022), 53–61. ISBN: 978-1-4503-9820-6. DOI: 10.1145/3568444.3568459

### 5.3.2 Augmenting Captioned Viewing

Another scenario that lends itself very well to language learning is watching movies and TV series with captions. Captions foster language comprehension, vocabulary learning, and (to some extent) also grammar learning [71, 110]. However, the caption designs currently available in online streaming services are usually not optimised for language learning, and this creates a barrier to viewing foreign-language media in everyday life. For example, switching captions on or off is a binary decision, with no option to remove potentially superfluous and distracting information, such as sound descriptions (e.g. “footsteps approaching”). The caption content and display are not adapted to a learner’s prior knowledge. Sometimes, there are also mismatches between what is spoken and what is written in the caption text, or captions are out of sync. Enhanced caption types such as keyword captions, keywords highlights, and time synchronisation promise to foster language learning [71]. Nevertheless, learners will only adopt advanced captions in their everyday viewing if they do not affect their viewing experience.

Therefore, in [P3.3], we investigated learners’ experiences with and attitudes towards standard and enhanced captions types. Based on literature research, a focus group, and a survey on caption usage, we identified promising caption types: (1) *time-synchronised keyword highlights*, (2) *full captions with keyword highlights*, and (3) f*ull captions with time-synchronised keyword highlights*.

With time synchronisation, we aimed to improve language comprehension because the written and spoken words can be matched more easily; keyword captions increase the focus on target words [34].

In an online study with 49 participants, we then assessed the user experience, perceived comprehension, perceived learning, and vocabulary retention with the three enhanced caption types and standard captions. The time-synchronised captions were highly rated for user experience, but contrary to our expectations, they did not outperform standard captions for language and content comprehension. In fact, learners felt they caused too much of a distraction. Keyword-only captions were the least favourite caption type because of the lack of context, which affected comprehension.

Overall, the paper confirms that a support technique such as captions may be helpful from a learning perspective, but this is often not enough to overturn habits. Especially when it comes to leisure activities where the primary focus is entertainment, not necessarily learning, a focus on seamless experiences is key to successful adoption.

> Fiona Draxler, Henrike Weingärtner, Maximiliane Windl, Albrecht Schmidt, and Lewis L. Chuang. 2023. Useful but distracting: keyword highlights and time-synchronization in captions for language learning. In Publisher: arXiv Version Number: 1. DOI: 10.48550/ARXIV.2307.05870

## 5.4 Auto-Generating Learning Material from the Context

*RQ 4: What are learner needs and preferences in the auto-generation of personally relevant learning material from learner contexts?*

The examples of augmented reading and viewing relied on existing media. However, it is also possible to generate learning material from scratch. This takes personalisation one step further and makes it possible to consider individual and situational interests. We explored this space in several steps, moving from marker-based Augmented Reality (AR) to high-quality object detection to turn a learner's environment into a learning opportunity. Table 5.1 gives an overview of the technological approaches and learning goals. In particular, we focused on the learner experience as a prerequisite for successful long-term learning. We studied the acceptance, usefulness, and real-life usage of such technologies. This paves the way for similar approaches that could, in the future, be used on head-mounted displays without explicit activation.

### 5.4.1 Grammar Learning with Augmented Reality

The first work conducted in this area built on ideas by Vazquez et al. [112] and Ibrahim et al. [49], who proposed vocabulary learning by adding AR labels to objects in a learner's surroundings. In our variant, we extended learning exercises to study German case grammar. In a mobile app, we used markers to detect objects in a camera preview. We automatically constructed sentences with user-selected objects and omitted articles to form multiple-choice quizzes.

We conducted a lab study with 25 participants to compare the AR version of our app to a static "snapshot" variant that provided camera preview screenshots of the real objects and their labels in the AR version and included the same multiple-choice quizzes in a static list. Despite the higher level of learner engagement required to generate quizzes in the AR version (and potentially deeper levels of processing, cf. Section 2.3.3), the performance on grammar tests was not better than in the snapshot version.

**Table 5.1** **Overview of technology approaches for generating context-aware learning material.**

| | Function & Implementation | Learning Goal |
|---|---|---|
| [P4.1] | • Object detection → Marker-based AR<br>• Position detection → Bounding box comparison<br>• Caption generation → Caption templates | Case Grammar |
| [P4.2] | • Object detection → Tensorflow Lite model (mobile)<br>• Position detection → Bounding box comparison<br>• Caption generation → Caption templates | Case Grammar |
| [P4.3] | • Object detection → Google Vision API<br>• Image retrieval → Pexels API<br>• Automatic translation → Google Translate API<br>• Speech synthesis → Android Text to Speech | Vocabulary: nouns and associated verbs |
| [P4.4] | • Object detection → Google Vision API<br>• Position detection → Bounding box comparison<br>• Caption generation → Google Translate API<br>• Caption generation → Caption templates | Case Grammar |

However, we could observe different learning strategies: participants in the AR condition spent more time exploring, while those in the static condition often repeated the same questions several times. In addition, when asked about situations where participants could imagine using the respective apps, the listed usage scenarios for the AR version were less location-dependent. This suggests that AR and dynamic exercises could be used for exploratory learning scenarios, e.g. for learning about new objects, while a static app may be sufficient and less distracting for revising content.

Fiona Draxler, Audrey Labrie, Albrecht Schmidt, and Lewis L. Chuang. 2020. Augmented reality to enable users in learning case grammar from their real-world interactions. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. CHI '20: CHI Conference on Human Factors in Computing Systems. ACM, Honolulu HI USA, (Apr. 21, 2020), 1–12. ISBN: 978-1-4503-6708-0. DOI: 10.1145/3313831.3376537

This paper received an **Honourable Mention Award** (Top 5% of submissions).

As a next step, we followed up on smartphone-based AR for grammar learning by implementing an app that performed markerless object detection. This work focused on the implementation of object detection and interaction patterns and was published as a demonstration paper [P4.2]. In particular, we applied on-device object detection with a Tensorflow Lite model. The model was able to distinguish the 80 classes of everyday objects available in the COCO data set[2], a typical database used for benchmarking computer vision algorithms. No internet connection was necessary, because all computations were executed directly on the mobile device. However, the comparatively low computing power on mobile devices and the application in uncontrolled environments meant that the accuracy of the generated exercises was not perfect. Nonetheless,

[2] https://cocodataset.org/

it was a well-suited artefact for several student projects (unpublished as of yet) that extended the app to optimise usability, evaluate automatically generated exercises, and study mitigation strategies for AI errors. A notable later update was a larger Tensorflow Lite model, trained on the Google Open Images data set[3] with 600 object classes. The current source code is available on GitHub[4].

> Fiona Draxler, Elena Wallwitz, Albrecht Schmidt, and Lewis L. Chuang. 2020. An environment-triggered augmented-reality application for learning case grammar. In *DELFI 2020 – Die 18. Fachtagung Bildungstechnologien der Gesellschaft für Informatik e.V.* Raphael Zender, Dirk Ifenthaler, Thiemo Leonhardt, and Clara Schumacher, editors. Gesellschaft für Informatik e.V., Bonn, 389–390. https://dl.gi.de/handle/20.500.12116/34202

### 5.4.2 Multimedia Learning with Off-the-Shelf Algorithms

[P4.1] had given some first insights into content generation in a pre-defined setup—but what are the effects of personalisation if we remove the constraint of a lab study and give learners the possibility to use an app at home, at their own pace, generating learning content from any chosen motif?

To this end, we developed Learning by Exploring, a mobile learning app that combined several algorithms for generating personalised learning material and conducted an in-situ study with 25 children. App users could add new learning material for learning English by taking a photo of their surroundings. We then automatically labelled this image with state-of-the-art object detection, queried a German label translation, provided sound via text-to-speech processing, and added an image from an online photo database. Additionally, learners could add verbs to the detected nouns, which we automatically translated. Different quiz types (i.e. translation, association) enabled interactive revision of the learning material. The children in our study enjoyed working with the app, but we found no improvements in terms of engagement and recall in comparison to a baseline group with comparable static learning content. According to the interviews, the children enjoyed the independence gained with the app, but a major issue was the quality of the image labelling.

We also analysed the learning material generated during the study in more detail. The generated multimedia learning material was correct in a majority of cases. Nevertheless, one reason for the low perceived quality may have been the label extraction for non-salient details of a photographed scene, e.g. wooden floors or table surfaces rather than the items placed on them. Other photographs were blurry, which affected detection quality. Another factor was the learners' prior knowledge: the children were between 9 and 12 years old and often misspelt the verbs they typed in to associate them with detected objects. This sometimes caused incorrect translations.

This analysis shows that even when an algorithm such as image labelling works well in static contexts, there are additional challenges in everyday usage. To some extent, these imperfections can be compensated with redundant representations: the combination of detected labels, retrieved images, and label translations all referring to the same item meant that if one representation was incorrect, users still had the means to identify such errors.

[3] https://storage.googleapis.com/openimages/web/index.html
[4] https://github.com/fionade/case-ar

Overall, this project helped us detect challenges in the interaction design when working with personalisation and automation. Children were an interesting target group because the concrete vocabulary-focused learning material was relevant for their prior knowledge, but also because it confronted our system with spelling mistakes and blurry images and showed how important it is to consider this in the experience design.

Fiona Draxler, Laura Haller, Albrecht Schmidt, and Lewis L. Chuang. 2022. Auto-generating multimedia language learning material for children with off-the-shelf AI. In *Mensch und Computer 2022*. MuC '22: Mensch und Computer 2022. ACM, Darmstadt Germany, (Sept. 4, 2022), 96–105. ISBN: 978-1-4503-9690-5. DOI: 10.1145/3543758.3543777

### 5.4.3 Relevance, Effort, and Perceived Quality in Content Generation

One of the main promises of contextual content generation is that personalisation improves learning. However, [P4.3] already showed that even when personally generated learning material is technically correct, it may not live up to learners' expectations. Hence, in [P4.4], we asked if learners actually find contextually personalised auto-generation of learning materials helpful and what factors this depends on. As before, we conducted an in-situ study where 64 learners used different versions of a self-developed mobile learning app: the participants in the *auto-personalised group* used a version that was similar to Learning by Exploring, with grammar exercises generated from learners' photographs with state-of-the-art object detection. A second version (*auto-learnersourced group*) included the same generated learning material, but instead of taking their own photographs, users retrieved the material from a list crowdsourced from the participants in the first group. The third group (*manual-learnersourced*) could also choose from the same list of photographs but this time, we had created grammar exercises manually.

Interestingly, participants in the *auto-personalised group* considered the relevance, correctness, and understandability of the generated exercises to be lower than participants in the two other groups. This means that the exact same content was rated worse when it was personalised than when it originated from a learnersourced list and was not connected to a learner's context. On the other hand, engagement and test performance were comparable across conditions. Possible reasons for the discrepancy in quality perception are prior expectations and effort. Notably, expectations may have been violated because the object detection was not correct or the algorithm did not pick up on the objects that learners wanted to target. In addition, taking photographs from within the app took longer than simply tapping on an image to add it to one's personal corpus.

In sum, this project confirmed that while personalisation is helpful in theory, implementation in practice is more complex. For personalisation to be successful and beneficial, it is essential to keep the effort on the user side as low as possible, and that content-generation systems function with imperfect algorithms. Even though intelligent algorithms for content generation are continuously improving, it is very unlikely that they will reach perfection in the near future. We propose several mitigation strategies, including information redundancy, crowdsourcing, and hybrid systems combining default material with personalised material.

Fiona Draxler, Albrecht Schmidt, and Lewis L. Chuang. 2023. Relevance, effort, and perceived quality: language learners' experiences with AI-generated contextually personalized learning material. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference*. DIS '23: Designing Interactive Systems Conference. ACM, Pittsburgh PA USA, (July 10, 2023), 2249–2262. ISBN: 978-1-4503-9893-0. DOI: 10.1145/3563657.3596112

# 6 Discussion

This section first summarises the findings from our research contributions and situates them within the domain of context-aware personalisation in self-directed ubiquitous learning. Based on this, I construct a framework of context-aware technology as a mediator between learners and their context and environment.

## 6.1 Summary of Contributions

The publications in this dissertation showcase how technology mediates between learners and their context. In this section, I summarise concrete takeaways with respect to the research questions formulated in Chapter 3. Based on the research questions, I then operationalise the respective mediating roles of technology.

### 6.1.1 RQ 1: When, where, and how do mobile learners study in everyday contexts?

(Mobile) learning sessions in everyday settings occur at different locations and times of day and are typically only a few minutes long. Learners are frequently interrupted, which often leads to them dropping the learning session. This fragmented learning has negative impacts on long-term engagement. Moreover, the fragmentation makes it challenging to convey topics with high levels of element interactivity. Sensing technology can provide information on the learner context that is valuable for adapting the content presentation or the interaction with the learner. For example, detecting interruptions in the learner process can be used to determine if resumption support is necessary. When returning to a learning session, learning systems could then present a resumption cue that helps them recall the learning context.

In the context of RQ 1, technology serves as a *sensing* mediator that collects information on the learner context and adapts the presentation of a learning experience.

### 6.1.2 RQ 2: How can we link opportune learning moments with context-aware learning triggers?

To achieve long-term engagement, learners need triggers that remind them to study at suitable times, matching situations to learning targets. Technology can provide learning reminders, e.g., push notifications on mobile devices triggered by a learner's current context. For high compliance rates, reminders should capture moments of availability and willingness to engage. For example, a promising approach is combining context sensing with user habits and matching the learning exercises to the learner context.

Thus, in the context of RQ 2, technology serves as a *triggering* mediator that links opportune moments and learning experiences depending on the learner's current context.

### 6.1.3 RQ 3: What are learner needs and preferences in the augmentation of everyday activities for enabling learning?

Everyday activities such as foreign-language reading and viewing can be augmented for language learning. Nonetheless, learners need carefully designed support to maintain enjoyment and, thus, (long-term) engagement. In particular, minimal designs and simple interaction patterns reduce disruptions. Providing learners with case-specific on-demand support avoids the error-prone process of capturing a learner's exact prior knowledge. Moreover, the power of

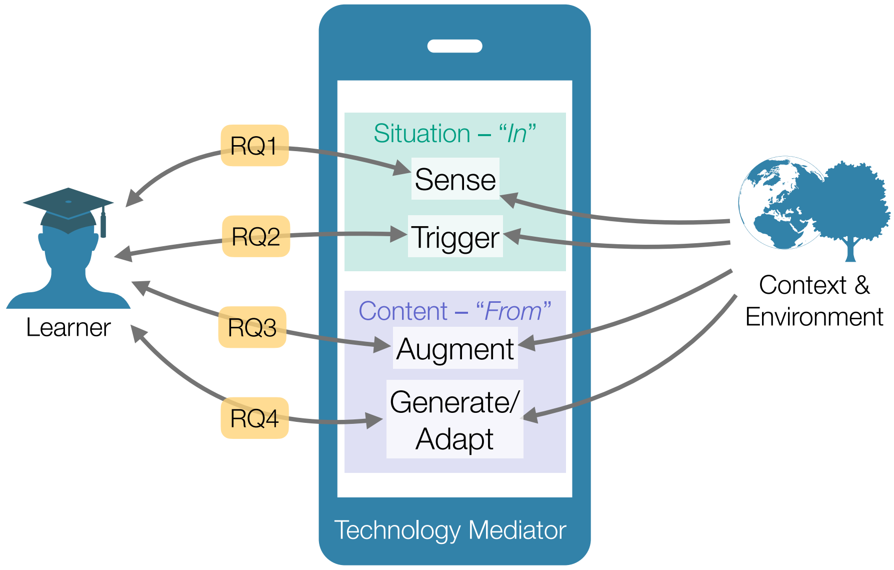


**Figure 6.1** **The mediating roles of interactive technology in context-aware ubiquitous learning.**

habits should not be underestimated: sometimes, it may be preferable to opt for patterns that learners are already used to rather than introducing a new one (e.g. default captions instead of learning-focused versions). Here, the danger of discouraging learners may outweigh the potential learning benefits.

In the context of RQ 3, technology serves as an *augmenting* mediator that turns everyday-life situations into learning opportunities by adding learning content.

### 6.1.4 RQ 4: What are learner needs and preferences in the auto-generation of personally relevant learning material from learner contexts?

Current capabilities of intelligent algorithms such as object detection make it possible to generate personalised material for ubiquitous learning from a learner's context. This provides flexible, individually relevant learning opportunities, in particular, for exploratory learning scenarios. However, there are several important factors that, if not addressed, may compromise the benefit of personalisation. First, systems that generate learning material need to minimise the effort on the learner side. This includes, for example, the selection of relevant targets from their context. Second, learner expectations in personalisation need to be taken into account: only when generated material is well-matched to a contextual target will learners actually consider the quality sufficient. Third, mechanisms should be in place that enable learners to identify and correct generation errors, e.g. by providing redundant information.

In the context of RQ 4, technology serves as a *generating* mediator that creates context-based learning material.

## 6.2 A Framework of Technology as a Mediator for Context-Aware Ubiquitous Learning

Through the research questions addressed in this thesis, we can derive a framework of the various mediating roles of technology for learning *In* and *From* everyday contexts. This framework extends the criteria of the ubiquitous context-aware learning space formulated by Hwang et al.

[48] by formalising concrete adaptation methods. It supports researchers in designing learning experiences and identifying research opportunities.

Figure 6.1 shows the complete version of the framework, including the mediating roles *sensing*, *triggering*, *augmenting*, and *generating/adapting*. The applications of technology-mediated learning within this framework differ in their target (either situation or content) and the method of real-world connection. For each role, I add guiding questions as a checklist for designing context-aware learning experiences[1] and provide two application examples: one derived from my research contributions and one scenario for a different application domain, taken from or inspired by related work. Note that technology can also take on several roles in a single scenario, and roles may overlap.

***Sensing*** In this role, technology collects the context characteristics of learning situations and uses this information to adapt the presentation of learning experiences, e.g. by adjusting learning paths based on cognitive variables or providing additional support after an interruption. The learner may or may not be aware of adaptations. The following questions define sensing applications:

1. *What are the learning targets and goals?*
2. *What are the characteristics of the learning material?* This can include aspects such as media types and the level of element interactivity.
3. *What intrinsic and extrinsic characteristics define the learner context?* This can include aspects such as the learner's prior knowledge, attention state, current location, the location's noise level, and social setting.
4. *What impact do the context characteristics and material characteristics have on the learning experience?*
5. *How can the presentation be adapted to optimise learning given the context characteristics and learning materials?*

For example, in the mobile learning setting of [P1.1], learning targets were individual for each participant (1). However, most mobile learning apps they used applied microlearning principles (2). We sensed and queried the time of day, the learners' location, their current social setting, device activity such as received push notifications, and detected movement types (3). The context characteristics influenced the occurrence of interruptions and the duration and frequency of mobile learning sessions (4). As investigated in [P1.2], technology could adapt to interruptions by presenting resumption cues that restore the learning context after an interruption (5). Relatedly, Schneegass et al. [93] provide examples of adapting learning sessions to the location, time of day, etc.

Another typical approach to sensing scenarios utilises intelligent tutoring systems. For example, Ritter et al. [82] employed Cognitive Tutor for mathematics education (1, 2). They tracked learner interaction to sense the learners' cognitive state and progress (3). These intrinsic context factors influence the learners' performance (4). Accordingly, Cognitive Tutor selects problems with an appropriate difficulty level (5).

[1] The questions are numbered but not completely independent. For example, application scenarios influence the possible learning contents and vice versa.

***Triggering*** In this role, technology creates or detects context-aware learning opportunities and nudges learners to engage. A typical interaction pattern is one where learners accept or decline technology suggestions. The following questions guide the design of learning triggers:

1. *What are the learning targets and goals?*
2. *What are opportune learning moments where learners are available and ready to engage in a learning activity?* Note that there can be several situations for the same learning target or different aspects of the same target. Moments depend on the presentation modalities and the size of the content chunks, amongst others.
3. *What learner actions or context characteristics indicate an opportune moment?*
4. *How can we link the opportune moment and the learning material with a context-aware trigger?*

In our work, audio-based dialogue practice was one of the learning targets in [P2.1] (1). Opportune moments require that learners can listen to audio and are not engaged in competing activities (2). We identified the headphone plugin event as an indicator activity (3, 4) to trigger a push notification. Additional conditions could be added to decrease the number of false positives (headphones could also be plugged in for other activities), for example, possible time windows or locations.

Context-aware technology can also trigger on-demand support for learning in the workplace. For example, Fessl et al. [27] investigated reflective learning on time management (1). Suitable times for reflection are closely linked to time-management-related events in everyday work (2). Therefore, their reflection support app triggered notifications when specific events were detected, e.g. related to used resources (3). The study participants were then prompted to reflect on the detected event, generating insights from their personal experiences (4).

***Augmenting*** In this role, technology enhances activities that learners perform anyway by adding learning-relevant information. For example, a system proposes learning content based on the learner's activity, and learners toggle support levels. When designing for augmentations, the following questions support the process:

1. *What are the learning targets and goals?*
2. *What (everyday) activities and situations could be augmented for learning?*
3. *How can these activities and situations be augmented to match the learning target?* In other words, *what are the contextual links between the situations and the learning targets?*

For example, in [P3.1] and [P3.2], we aimed to convey grammatical concepts, namely adverbs versus adjectives and past tenses (1). Foreign-language reading is suitable because the targeted grammatical concepts frequently appear in narrated texts (2). E-readers provide the augmentation platform: they link the text and interactive support (3).

Augmentation is also well-suited for facilitating learning in entertainment video games. For example, Hobbs et al. [41] used Minecraft (2) to teach irrigation in agriculture and volcano eruptions (1). The instructors designed a Minecraft scenario and set goals for the learners, e.g. producing sufficient crops for a growing population (3). Working towards these goals in gameplay supports the learners' understanding of the target concepts (3).

***Generating and Adapting*** In this role, technology follows the learner's indication of interest to propose context-aware and personalised learning materials. Note that this also includes adapting existing learning materials to match the context, which follows a similar approach but represents a shallower context adaptation method. Guiding questions for generating and adapting are:

1. *What are the learning targets and goals?*
2. *What context elements are connected to the learning targets and goals?* Note that this can be concrete (e.g. objects) but also indirect (e.g. objects as anchors) or simulated (e.g. digital media) context elements.
3. *How can learners interact with the context to generate learning materials or modify them from the context?* In other words, *what interaction does the learning experience afford?*

In [P4.1], we targeted German case grammar (1). We utilised the connection of German nouns—which have a grammatical gender—to real-life objects (2). An AR interface established the connection: learners could position objects in real life and scan them with our app to create language quizzes (3).

Another scenario is the *modification* of templates to match the learner context. This is inspired by context personalisation and example choice, two approaches for adapting the framing of a learning task to learners' interests [43]. To adapt calculus exercises (1), Høgheim and Reber [43] asked students for information such as their favourite drink. Similarly, adaptations could also be based on concrete context elements, e.g. a water bottle that a student has brought with them (2). The learning system could ask learners to scan the room for suitable elements to fill in the blanks in generic exercise templates (3).

Taken together, this framework formalises the relationship between learners, technology, and context in context-aware ubiquitous learning. The guiding questions and examples highlight that context awareness can be achieved in many ways and for different purposes. Moreover, analysing prior work in light of the mediating roles reveals opportunities for future research. For example, only a small number of everyday activities are currently explicitly augmented for learning, although learners commonly engage in a variety of activities in different places.

# 7 Implications and Outlook

This thesis relied primarily on ubiquitous language learning for individuals. Below, we analyse the broader implications of our work, including perspectives of human-AI interaction. We discuss how our findings extend to different types of technology support and application domains and where additional work is needed.

## 7.1 Human-AI Collaboration in Learning and Beyond

Our findings closely relate to the ongoing discussion of human-AI collaboration in learning and beyond. More precisely, from our analyses of user perspectives on the interaction with an intelligent system, we can derive principles for interacting with systems that do not always perform optimally. Notably, we demonstrate that intelligent support is possible, even when the applied technology is imperfect (e.g. the object detection used in [P4.3, P4.4]) and even though learners are not an expert in the learning domain and cannot always detect errors in the technology. A key point here is the focus on simple interaction patterns to unlock the potential of the human-machine collaboration: Quick feedback loops enable autonomy for increased ownership [115] and keep efforts on the user side low. This is important because perceived effort impacts the probability of using a technology [113]. Moreover, redundant information facilitates error detection.

For example, the headphone plugin interaction we proposed in the *triggering* scenario in [P2.1] combines context sensing by a device with a one-step user action. Thus, even when not all detected events match an opportune moment for learning, the user effort for dealing with false positives is low. When low-effort solutions are hard to achieve, we recommend optimising for perceived effort. For example, in [P4.4], we proposed taking photos in a batch rather than one by one or gamified photo-taking challenges to reduce the perceived effort of taking pictures.

Similar ideas are also interesting for other domains where humans need to critically evaluate AI output. This includes fact-checking support for large language model hallucinations—a major challenge in natural language processing [50]—, and medical decision support systems, where mistakes can have fatal consequences.

Currently, several challenges lead to a trade-off between the versatility and scalability of context-based personalisation and its quality. First, with limited personalisation, it is easier to tailor learning content. For instance, the sentence templates we provided in [P4.1, P4.4] worked well because they were designed for the specific learning scenario but would be insufficient for a long-term study. Second, an intelligent system's objective and subjective performance do not always match. In particular, as we found in [P4.4], user expectations play a substantial role. Studies on auto-generated music [45] or art [15] have shown that similar effects also exist in other domains: prior expectations and attitudes towards AI influence the subjective rating of AI performance. Therefore, additional research is needed to identify determinants of perceived quality in personalisation.

Lastly, we expect that further developments of generative models will substantially change the landscape of AI support and lift personalisation to new levels, with numerous novel application scenarios in contextualised learning. This also means that user interfaces will evolve beyond the current generic chat- or prompt-based designs. In this line, our research contributions can provide guidance for specialised application design, e.g. with the abovementioned suggestions for minimal effort, interaction for perceived ownership, and means for error checking.

## 7.2 Expansion of Involved Devices: Mobile, AR, and the Future

The work presented in this thesis utilised smartphones and tablets as learning devices. This was the technology of choice because the devices are mobile, easily available, have attained a high standard, and because learners are often experienced users (cf. Section 2.5). Other technology, such as AR glasses and eye trackers, could have added to the ubiquitous experiences. However, factors such as a narrow field of view, low resolution, and uncomfortable wear limited their applicability in our studies, in particular, in-situ studies. As technology evolves, we expect these devices to become more capable and fit for everyday use. This will bring seamless learning to a new level, making Vazquez et al.'s vision of serendipitous mixed-reality learning in everyday life a reality [112].

Even with these changes, our research still provides a valuable basis for designing learning support in context. For instance, wearing AR goggles may extend the availability window for learning activities but not necessarily the willingness to actively engage. We expect individual engagement patterns to adapt to device usage habits, and similar pairings of learning triggers and activities as those in [P2.1] can be established.

Similarly, our findings in the context of embedding learning into everyday activities are relevant for avoiding information overload and providing case-based, context-matched assistance in similar scenarios. And while it may be easier to detect objects of interest in a learner's periphery, it is still important to devise minimal-effort interaction patterns that achieve correct and salient learning material, ultimately satisfying a learner's expectations and information needs. Here, the interaction patterns we present provide a useful starting point (e.g. for details on demand, redundancy, and correction).

## 7.3 Contextualised Learning Beyond Language

As explained in Section 2.5.3, we chose language learning as a sample use case for our perspectives on learning experiences. Nonetheless, learning content for other topics can just as well be anchored in real-world environments. For example, Section 6.2 lists several examples in different learning domains. Past work has also specifically explored mobile and ubiquitous technology as a mediator in physics education, augmenting the real world for learning. Kuhn and Vogt [58] proposed several experiments for learning about gravitation with smartphone sensors. Similarly, Hochberg et al. [42] evaluated the gyroscopes in mobile phones as sensors for pendulum experiments and found positive effects on the learners' level of interest.

So far, the scalability of content authoring remains a major limiting factor in many technology-supported learning experiences that generate personalised content [76, 103]. Solutions are often tailored towards a specific scenario, and authoring is a manual process requiring expertise in the learning domain and the applied technology (e.g. in [14, 49]). Content generation mechanisms like the ones presented in this work provide a basis for extensions to other domains, e.g. object detection for physics experiments. This could further extend the space of learning-analytics-based learning design [79] to context-aware learning situations.

## 7.4 Contextualised Learning Beyond Concreteness

One challenge that we have only partly addressed and discussed so far is abstractness, both in the sense of teaching abstract learning items (e.g. abstract vocabulary) and of concreteness fading (i.e. when progressing from concrete to abstract representations of a concept, cf. Section 2.1.5). Clearly, concrete links between everyday environments and learning contents are easier to capture. Therefore, they were a good starting point for our research. However, support for abstract learning is also necessary.

For abstract learning items, we have started to explore using concrete items as an anchor for abstract ones: for example, a learning system with object detection could retrieve extracts from books and other media that reference an object label but provide more context around it. Retrieved examples could be selected such that they also involve abstract concepts. Moreover, new examples could be created with generative models, e.g. by prompting a large language model to "Write a sentence that contains the words *tea cup* and *excitement*".

In the context of concreteness fading, learning support systems should provide concrete and abstract modes. For example, in [P4.1], we discussed how the primary use case of *generating* technology is exploring and collecting new learning material. At later learning stages, this can then be combined with more concept-focused activities that facilitate schema construction.

## 7.5 A Healthy Attitude Towards Learning

As researchers, we also need to consider social and ethical factors. Here, we briefly discuss well-being and social interaction, two notions that we consider particularly important for context-aware ubiquitous learning.

The concepts we propose in this thesis extend the notion of potential learning situations. However, this does not mean that every everyday activity and every opportune moment must indeed include learning. As mentioned in [P2.1], the total learning load should not overwhelm learners. Rather, we hope that embedding learning into everyday schedules makes it easier to make room for other activities without increasing the pressure to self-optimise. Identifying suitable windows could also make learning with high levels of element interactivity more effective, decreasing the necessary overall time investment. For future work, we recommend increased efforts in self-reflection and meta-cognition support for ubiquitous learning systems (see, e.g. [27, 62] for existing work).

Furthermore, the work we presented revolved around individual learning experiences. Nonetheless, learning is often a social experience. For example, this shows in the fact that communities of practice are seen as an integral component of situated learning [60]. Social aspects are also important for ubiquitous learning. For instance, benefits of collaboration have been observed in mobile learning settings, e.g. for language practice [59] and engagement through social interaction [63]. Conversely, the lack of social interactions in learning can cause a feeling of disconnectedness [22]. Future work should also focus on engaging learners in communities to avoid this. For example, the learnersourcing strategies we propose in [P4.4] can provide a starting point for social interactions in technology-mediated learning.

## 7.6 Learning in the Long Term

Our work primarily addressed learner factors such as user experience and engagement. However, we still lack an in-depth assessment of the long-term learning effects of personalisation in context-aware ubiquitous learning. This is due to several challenges in theoretical grounding, methodology, and technology. First, the interplay between cognitive science and technology is often a chicken-or-egg problem: technological advancements enable novel learning experiences whose working principles have not (yet) been theoretically confirmed or invalidated. However, the theoretical foundations cannot be laid without the respective technology support. Wizardof-Oz studies represent a workaround, but flexibility is limited, and they are best suited for lab studies. Second, as we pointed out in Chapter 4, measuring personalised learning in long-term settings is an empirical and technological challenge that needs to be tackled in more depth.

# 8 Collaboration Statement

The work presented in this thesis would not have been possible without the help of students, peers, and mentors. Table 8.1 summarises who collaborated with me and how in the various projects.

**Albrecht Schmidt** and **Lewis L. Chuang** supported me in most of my research work. They provided essential inspiration for the research questions and contributions and helped me frame them, reflect on them, and obtain a broader perspective on their implications. As these roles were consistent for all publications they co-authored, I will not list them individually.

When I supervised student research projects (bachelor's and master's theses, internships, and individual research projects), I defined the research objectives and guided the students' work in all stages, including the conceptualisation, implementation, hypothesis formulation and study design as well as the analysis of results.

All additional collaborations are listed in Table 8.1. In appreciation of these collaborations, I use the scientific "we" when I describe and analyse the research work conducted in the scope of this thesis.

**Table 8.1 My own and my colleagues' contributions to the papers that constitute this thesis (besides the continuous contributions of Albrecht Schmidt and Lewis L. Chuang).**

| Publication | Contributions |
|---|---|
| [P1.2] | **Christina Schneegass** and I developed the research idea, and we contributed equally to the focus group and concept analysis. **Evangelos Niforatos** supported us in refining and positioning our contribution within the research space. |
| [P3.1] | This work is based on **Nicole Lippner's** master's thesis, which I co-supervised with **Christina Schneegass**. Christina Schneegass and I prepared the manuscript based on the thesis, substantially extending the study analysis, visualisations, and discussion. |
| [P4.1] | **Audrey Labrie** implemented the Android apps for the user study under my guidance and with my feedback. She also conducted the user study with most of the participants and gave feedback on the paper. I wrote the draft of the paper and refined it based on my co-authors' comments. |
| [P4.2] | I implemented the Android app, which re-used some of the code that originated from **Elena Wallwitz's** bachelor's thesis. |
| [P1.1] | This work is based on **Jonas Safranek's** master's thesis, which I co-supervised with **Christina Schneegass**. Jonas Safranek implemented the app and conducted the study under our guidance. Christina Schneegass and I wrote the text, with my focus being on the data analysis and hers on the mitigation potential. **Heinrich Hussmann** supported us in refining the framing of the paper. |
| [P2.1] | This paper is based on **Julia Brenner's** and **Manuela Eska's** bachelor's theses. They implemented Android apps and coordinated the user studies. Building on their results, I extended the data analysis and wrote the majority of the paper. |
| [P2.2] | I was the sole author of this paper. The concept was inspired by discussions with **Albrecht Schmidt** and **Lewis L. Chuang**. |
| [P4.3] | This paper is based on **Laura Haller's** master's thesis. She implemented the Android app and conducted the user study under my guidance and with my feedback. I extended the analysis and wrote the paper. |
| [P3.2] | This paper is based on **Viktoriia Rakytianska's** master's thesis. She designed the e-reader prototype and conducted the study. I evaluated the data and wrote the paper. |
| [P4.4] | **Eleanor Colligan** supported me in the realisation of questionnaires and updated the evaluation scripts to match our revised study design. I conducted the data analysis and drafted and revised the paper. |
| [P3.3] | This paper is based on **Henrike Weingärtner's** master's thesis, which I co-supervised with **Maximiliane Windl**. I wrote the first version of the paper, and they both made corrections and suggested improvements. |

# 9 Conclusion

This thesis explored learner perspectives on context-aware ubiquitous learning *in* and *from* everyday contexts. We investigate four different roles in context-aware personalised learning that interactive technology can take on: sensing, triggering, augmenting, and generating. Through the lens of these roles, we explored learning opportunities, as well as learner needs and preferences. We find that context-aware technology can provide insights into everyday learning patterns, establish learning triggers that indicate availability and willingness, turn everyday activities into learning scenarios, and generate new learning material based on learner interests. We synthesise the four roles as a research framework and derive recommendations for the design of such technology to fully leverage the benefits of personalisation. This includes error mitigation strategies, adaptive support levels, and case-specific interaction patterns. The findings presented in this work also provide a basis for future work in other learning domains and application scenarios for human-AI interaction. The findings are particularly relevant in light of emerging technologies such as large language models that have already started to shape the landscape of learning.

# Contributing Publications


[P1.1] Fiona Draxler, Christina Schneegass, Jonas Safranek, and Heinrich Hussmann. 2021. Why did you stop? - Investigating origins and effects of interruptions during mobile language learning. In *Mensch und Computer 2021*. MuC '21: Mensch und Computer 2021. ACM, Ingolstadt Germany, (Sept. 5, 2021), 21–33. isbn: 978-1-4503-8645-6. doi: 10.1145/3473856.3473881.

[P1.2] Fiona Draxler, Christina Schneegass, and Evangelos Niforatos. 2019. Designing for task resumption support in mobile learning. In *Proceedings of the 21st International Conference on Human-Computer Interaction with Mobile Devices and Services*. MobileHCI '19: 21st International Conference on Human-Computer Interaction with Mobile Devices and Services. ACM, Taipei Taiwan, (Oct. 2019), 1–6. isbn: 978-1-4503-6825-4. doi: 10.1145/3338286.3344394.

[P2.1] Fiona Draxler, Julia Maria Brenner, Manuela Eska, Albrecht Schmidt, and Lewis L Chuang. 2022. Agenda- and activity-based triggers for microlearning. In *27th International Conference on Intelligent User Interfaces*. IUI '22: 27th International Conference on Intelligent User Interfaces. ACM, Helsinki Finland, (Mar. 22, 2022), 620–632. isbn: 978-1-4503-9144-3. doi: 10.1145/3490099.3511133.

[P2.2] Fiona Draxler. 2022. Using wearables to optimize learning at home. In *Sense, Feel, Design*. Vol. 13198. Carmelo Ardito et al., editors. Series Title: Lecture Notes in Computer Science. Springer International Publishing, Cham, 474–480. isbn: 978-3-030-98388-8. doi: 10.1007/978-3-030-98388-8_42.

[P3.1] Fiona Draxler, Christina Schneegass, Nicole Lippner, and Albrecht Schmidt. 2019. Exploring visualizations for digital reading augmentation to support grammar learning. In *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia - MUM '19*. the 18th International Conference. ACM Press, Pisa, Italy, 1–11. isbn: 978-1-4503-7624-2. doi: 10.1145/3365610.3365623.

[P3.2] Fiona Draxler, Viktoriia Rakytianska, and Albrecht Schmidt. 2022. Maintaining reading flow in e-readers with interactive grammar augmentations for language learning. In *Proceedings of the 21st International Conference on Mobile and Ubiquitous Multimedia*. MUM 2022: 21th International Conference on Mobile and Ubiquitous Multimedia. ACM, Lisbon Portugal, (Nov. 27, 2022), 53–61. isbn: 978-1-4503-9820-6. doi: 10.1145/3568444.3568459.

[P3.3] Fiona Draxler, Henrike Weingärtner, Maximiliane Windl, Albrecht Schmidt, and Lewis L. Chuang. 2023. Useful but distracting: keyword highlights and time-synchronization in captions for language learning. In Publisher: arXiv Version Number: 1. doi: 10.48550/ARXIV.2307.05870.

[P4.1] Fiona Draxler, Audrey Labrie, Albrecht Schmidt, and Lewis L. Chuang. 2020. Augmented reality to enable users in learning case grammar from their real-world interactions. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. CHI '20: CHI Conference on Human Factors in Computing Systems. ACM, Honolulu HI USA, (Apr. 21, 2020), 1–12. isbn: 978-1-4503-6708-0. doi: 10.1145/3313831.3376537.

[P4.2] Fiona Draxler, Elena Wallwitz, Albrecht Schmidt, and Lewis L. Chuang. 2020. An environment-triggered augmented-reality application for learning case grammar. In *DELFI 2020 – Die 18. Fachtagung Bildungstechnologien der Gesellschaft für Informatik e.V.* Raphael Zender, Dirk Ifenthaler, Thiemo Leonhardt, and Clara Schumacher, editors. Gesellschaft für Informatik e.V., Bonn, 389–390. https://dl.gi.de/handle/20.500.12116/34202.

[P4.3] Fiona Draxler, Laura Haller, Albrecht Schmidt, and Lewis L. Chuang. 2022. Auto-generating multimedia language learning material for children with off-the-shelf AI. In *Mensch und Computer 2022*. MuC '22: Mensch und Computer 2022. ACM, Darmstadt Germany, (Sept. 4, 2022), 96–105. ISBN: 978-1-4503-9690-5. DOI: 10.1145/3543758.3543777.

[P4.4] Fiona Draxler, Albrecht Schmidt, and Lewis L. Chuang. 2023. Relevance, effort, and perceived quality: language learners' experiences with AI-generated contextually personalized learning material. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference*. DIS '23: Designing Interactive Systems Conference. ACM, Pittsburgh PA USA, (July 10, 2023), 2249–2262. ISBN: 978-1-4503-9893-0. DOI: 10.1145/3563657.3596112.

# References


[1] Vincent Aleven, Elizabeth A McLaughlin, R Amos Glenn, and Kenneth R Koedinger. 2016. Instruction based on adaptive learning technologies. *Handbook of research on learning and instruction*, 522–560. Publisher: Routledge New York, NY.

[2] Alan Baddeley. 1983. Working memory. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*, 302, 1110, (Aug. 11, 1983), 311–324. DOI: 10.1098/rstb.1983.0057.

[3] Alan Baddeley. 2012. Working memory: theories, models, and controversies. *Annual Review of Psychology*, 63, 1, (Jan. 10, 2012), 1–29. DOI: 10.1146/annurev-psych-120710-100422.

[4] Jennifer S. Beaudin, Stephen S. Intille, Emmanuel Munguia Tapia, Randy Rockinson, and Margaret E. Morris. 2007. Context-sensitive microlearning of foreign language vocabulary on a mobile device. In *Ambient Intelligence*. Bernt Schiele, Anind K. Dey, Hans Gellersen, Boris De Ruyter, Manfred Tscheligi, Reiner Wichert, Emile Aarts, and Alejandro Buchmann, editors. Red. by David Hutchison et al. Vol. 4794. Series Title: Lecture Notes in Computer Science. Springer Berlin Heidelberg, Berlin, Heidelberg, 55–72. ISBN: 978-3-540-76652-0. DOI: 10.1007/978-3-540-76652-0_4.

[5] Niels Van Berkel, Denzil Ferreira, and Vassilis Kostakos. 2017. The experience sampling method on mobile devices. *ACM Computing Surveys*, 50, 6, (Dec. 6, 2017), 1–40. DOI: 10.1145/3123988.

[6] Elizabeth L Bjork, Robert A Bjork, et al. 2011. Making things hard on yourself, but in a good way: creating desirable difficulties to enhance learning. *Psychology and the real world: Essays illustrating fundamental contributions to society*, 2, 59.

[7] Judith Borghouts, Duncan P. Brumby, and Anna L. Cox. 2020. TimeToFocus: Feedback on Interruption Durations Discourages Distractions and Shortens Interruptions. en. *ACM Transactions on Computer-Human Interaction*, 27, 5, (Oct. 2020), 1–31. DOI: 10.1145/3396044.

[8] David W. Braithwaite and Robert L. Goldstone. 2013. Integrating formal and grounded representations in combinatorics learning. *Journal of Educational Psychology*, 105, 3, 666–682. DOI: 10.1037/a0032095.

[9] John Brooke et al. 1996. SUS-a quick and dirty usability scale. *Usability evaluation in industry*, 189, 194, 4–7.

[10] John Seely Brown, Allan Collins, and Paul Duguid. 1989. Situated cognition and the culture of learning. *Educational researcher*, 18, 1, 32–42. DOI: 10.3102/0013189X018001032.

[11] Jack Burston. 2015. Twenty years of MALL project implementation: a meta-analysis of learning outcomes. *ReCALL*, 27, 1, (Jan. 2015), 4–20. DOI: 10.1017/S0958344014000159.

[12] Carrie J. Cai, Anji Ren, and Robert C. Miller. 2017. WaitSuite: productive use of diverse waiting moments. *ACM Transactions on Computer-Human Interaction*, 24, 1, (Mar. 22, 2017), 1–41. DOI: 10.1145/3044534.

[13] Nicholas J. Cepeda, Harold Pashler, Edward Vul, John T. Wixted, and Doug Rohrer. 2006. Distributed practice in verbal recall tasks: a review and quantitative synthesis. *Psychological Bulletin*, 132, 3, 354–380. DOI: 10.1037/0033-2909.132.3.354.

[14] Alan Y. Cheng et al. 2023. Designing immersive, narrative-based interfaces to guide outdoor learning. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. CHI '23: CHI Conference on Human Factors in Computing Systems. ACM, Hamburg Germany, (Apr. 19, 2023), 1–22. ISBN: 978-1-4503-9421-5. DOI: 10.1145/3544548.3581365.

[15] Salvatore G. Chiarella, Giulia Torromino, Dionigi M. Gagliardi, Dario Rossi, Fabio Babiloni, and Giulia Cartocci. 2022. Investigating the negative bias towards artificial intelligence: effects of prior assignment of AI-authorship on the aesthetic appreciation of abstract paintings. *Computers in Human Behavior*, 137, (Dec. 2022), 107406. DOI: 10.1016/j.chb.2022.107406.

[16] Maria Chinkina, Simón Ruiz, and Detmar Meurers. 2017. Automatically generating questions to support the acquisition of particle verbs: evaluating via crowdsourcing. In *CALL in a climate of change: adapting to turbulent global conditions – short papers from EUROCALL 2017*. Kate Borthwick, Linda Bradley, and Sylvie Thouësny, editors. Research-publishing.net, (Dec. 3, 2017), 73–78. ISBN: 978-2-490-05704-7. DOI: 10.14705/rpnet.2017.eurocall2017.692.

[17] Dorothy M. Chun and Jan L. Plass. 1996. Effects of multimedia annotations on vocabulary acquisition. *The Modern Language Journal*, 80, 2, (June 1996), 183–198. DOI: 10.1111/j.1540-4781.1996.tb01159.x.

[18] Analía Cicchinelli, Eduardo Veas, Abelardo Pardo, Viktoria Pammer-Schindler, Angela Fessl, Carla Barreiros, and Stefanie Lindstädt. 2018. Finding traces of self-regulated learning in activity streams. In *Proceedings of the 8th International Conference on Learning Analytics and Knowledge*. LAK '18: International Conference on Learning Analytics and Knowledge. ACM, Sydney New South Wales Australia, (Mar. 7, 2018), 191–200. ISBN: 978-1-4503-6400-3. DOI: 10.1145/3170358.3170381.

[19] James M. Clark and Allan Paivio. 1991. Dual coding theory and education. *Educational psychology review*, 3, 3, 149–210.

[20] T. De Pessemier, K. De Moor, W. Joseph, L. De Marez, and L. Martens. 2013. Quantifying the influence of rebuffering interruptions on the user's quality of experience during mobile video watching. *IEEE Transactions on Broadcasting*, 59, 1, (Mar. 2013), 47–61. DOI: 10.1109/TBC.2012.2220231.

[21] Tilman Dingler, Dominik Weber, Martin Pielot, Jennifer Cooper, Chung-Cheng Chang, and Niels Henze. 2017. Language learning on-the-go: opportune moments and design of mobile microlearning sessions. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI '17*. the 19th International Conference. ACM Press, Vienna, Austria, 1–12. ISBN: 978-1-4503-5075-4. DOI: 10.1145/3098279.3098565.

[22] Fiona Draxler, Linda Hirsch, Jingyi Li, Carl Oechsner, Sarah Theres Völkel, and Andreas Butz. 2022. Flexibility and social disconnectedness: assessing university students' well-being using an experience sampling chatbot and surveys over two years of COVID-19. In *Designing Interactive Systems Conference*. DIS '22: Designing Interactive Systems

Conference. ACM, Virtual Event Australia, (June 13, 2022), 217–231. ISBN: 978-1-4503-9358-4. DOI: 10.1145/3532106.3533537.

[23] Tobias Drey, Pascal Jansen, Fabian Fischbach, Julian Frommel, and Enrico Rukzio. 2020. Towards progress assessment for adaptive hints in educational virtual reality games. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*. CHI '20: CHI Conference on Human Factors in Computing Systems. ACM, Honolulu HI USA, (Apr. 25, 2020), 1–9. ISBN: 978-1-4503-6819-3. DOI: 10.1145/3334480.3382789.

[24] Matt Dunleavy and Chris Dede. 2014. Augmented reality teaching and learning. In *Handbook of Research on Educational Communications and Technology*. J. Michael Spector, M. David Merrill, Jan Elen, and M. J. Bishop, editors. Springer New York, New York, NY, 735–745. ISBN: 978-1-4614-3185-5. DOI: 10.1007/978-1-4614-3185-5_59.

[25] John Dunlosky, Katherine A. Rawson, Elizabeth J. Marsh, Mitchell J. Nathan, and Daniel T. Willingham. 2013. Improving students' learning with effective learning techniques: promising directions from cognitive and educational psychology. *Psychological Science in the Public Interest*, 14, 1, (Jan. 2013), 4–58. DOI: 10.1177/1529100612453266.

[26] Darren Edge, Elly Searle, Kevin Chiu, Jing Zhao, and James A. Landay. 2011. MicroMandarin: mobile language learning in context. en. In *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11*. ACM Press, Vancouver, BC, Canada, 3169. ISBN: 978-1-4503-0228-9. DOI: 10.1145/1978942.1979413.

[27] Angela Fessl, Gudrun Wesiak, Veronica Rivera-Pelayo, Sandra Feyertag, and Viktoria Pammer. 2017. In-app reflection guidance: lessons learned across four field trials at the workplace. *IEEE Transactions on Learning Technologies*, 10, 4, (Oct. 1, 2017), 488–501. DOI: 10.1109/TLT.2017.2708097.

[28] Samuel G. Finlayson, Hyunkwang Lee, Isaac S. Kohane, and Luke Oakden-Rayner. 2018. Towards generative adversarial networks as a new paradigm for radiology education. (Dec. 4, 2018). Retrieved Oct. 17, 2022 from http://arxiv.org/abs/1812.01547 arXiv: 1812.01547[cs].

[29] Gustavo García Botero, Frederik Questier, and Chang Zhu. 2019. Self-directed language learning in a mobile-assisted, out-of-class context: do students walk the talk? *Computer Assisted Language Learning*, 32, 1, (Jan. 2, 2019), 71–97. DOI: 10.1080/09588221.2018.1485707.

[30] Elena L. Glassman, Aaron Lin, Carrie J. Cai, and Robert C. Miller. 2016. Learnersourcing personalized hints. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing - CSCW '16*. the 19th ACM Conference. ACM Press, San Francisco, California, USA, 1624–1634. ISBN: 978-1-4503-3592-8. DOI: 10.1145/2818048.2820011.

[31] Duncan R Godden and Alan D Baddeley. 1975. Context-dependent memory in two natural environments: on land and underwater. *British Journal of Psychology*, 66, 3, 325–331. DOI: 10.1111/j.2044-8295.1975.tb01468.x.

[32] Robert Godwin-Jones. 2018. Chasing the butterfly effect: informal language learning online as a complex system. *Language Learning & Technology*, 22, 2, 8–27.

[33] Tom Gross and Anna-Lena Mueller. 2021. NotificationManager: Personal Boundary Management on Mobile Devices. en. In *Human-Computer Interaction – INTERACT 2021*. Vol. 12935. Carmelo Ardito, Rosa Lanzilotti, Alessio Malizia, Helen Petrie, Antonio Piccinno, Giuseppe Desolda, and Kori Inkpen, editors. Series Title: Lecture Notes in

Computer Science. Springer International Publishing, Cham, 243–261. ISBN: 978-3-030-85610-6. DOI: 10.1007/978-3-030-85610-6_15.

[34] Helen Gant Guillory. 1998. The effects of keyword captions to authentic French video on learner comprehension. *Calico Journal*, 89–108.

[35] Judith M. Harackiewicz, Jessi L. Smith, and Stacy J. Priniski. 2016. Interest matters: the importance of promoting interest in education. *Policy Insights from the Behavioral and Brain Sciences*, 3, 2, (Oct. 2016), 220–227. DOI: 10.1177/2372732216655542.

[36] Mohammad Nehal Hasnine, Brendan Flanagan, Gokhan Akcapinar, Hiroaki Ogata, Kousuke Mouri, and Noriko Uosaki. 2019. Vocabulary learning support system based on automatic image captioning technology. In *Distributed, Ambient and Pervasive Interactions*. Vol. 11587. Norbert Streitz and Shin'ichi Konomi, editors. Series Title: Lecture Notes in Computer Science. Springer International Publishing, Cham, 346–358. ISBN: 978-3-030-21935-2. DOI: 10.1007/978-3-030-21935-2_26.

[37] Ari Hautasaari, Takeo Hamada, Kuntaro Ishiyama, and Shogo Fukushima. 2019. VocaBura: a method for supporting second language vocabulary learning while walking. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 3, 4, (Dec. 11, 2019), 1–23. DOI: 10.1145/3369824.

[38] Catherine Regina Heil, Jason S. Wu, Joey J. Lee, and Torben Schmidt. 2016. A review of mobile language learning applications: trends, challenges, and opportunities. *The EuroCALL Review*, 24, 2, (Sept. 30, 2016), 32–50. DOI: 10.4995/eurocall.2016.6402.

[39] Suzanne Hidi and K. Ann Renninger. 2006. The four-phase model of interest development. *Educational Psychologist*, 41, 2, (June 2006), 111–127. DOI: 10.1207/s15326985ep4102_4.

[40] James M. Higgins. 1996. Innovate or evaporate: creative techniques for strategists. *Long Range Planning*, 29, 3, (June 1996), 370–380. DOI: 10.1016/0024-6301(96)00023-4.

[41] Laura Hobbs, Carly Stevens, Jackie Hartley, and Calum Hartley. 2019. Science hunters: an inclusive approach to engaging with science through minecraft. *Journal of Science Communication*, 18, 2, (Feb. 11, 2019), N01. DOI: 10.22323/2.18020801.

[42] Katrin Hochberg, Jochen Kuhn, and Andreas Müller. 2018. Using smartphones as experimental tools—effects on interest, curiosity, and learning in physics education. *Journal of Science Education and Technology*, 27, 5, (Oct. 2018), 385–403. DOI: 10.1007/s10956-018-9731-7.

[43] Sigve Høgheim and Rolf Reber. 2017. Eliciting mathematics interest: new directions for context personalization and example choice. *The Journal of Experimental Education*, 85, 4, (Oct. 2, 2017), 597–613. DOI: 10.1080/00220973.2016.1268085.

[44] Nina Hollender, Cristian Hofmann, Michael Deneke, and Bernhard Schmitz. 2010. Integrating cognitive load theory and concepts of human-computer interaction. *Computers in Human Behavior*, 26, 6, (Nov. 2010), 1278–1288. DOI: 10.1016/j.chb.2010.05.031.

[45] Joo Wha Hong, Qiyao Peng, and Dmitri Williams. 2021. Are you ready for artificial mozart and skrillex? an experiment testing expectancy violation theory and AI music. *New Media & Society*, 23, 7, (July 2021), 1920–1935. DOI: 10.1177/1461444820925798.

[46] Chester S. J. Huang, Stephen J. H. Yang, Tosti H. C. Chiang, and Addison Y. S. Su. 2016. Effects of situated mobile learning approach on learning motivation and performance of EFL students. *Journal of Educational Technology & Society*, 19, 1, 263–276. Publisher:

International Forum of Educational Technology & Society. http://www.jstor.org/stable/jeductechsoci.19.1.263.

[47] Theo Hug. 2010. Mobile learning as 'microlearning': conceptual considerations towards enhancements of didactic thinking. *International Journal of Mobile and Blended Learning*, 2, 4, (Oct. 2010), 47–57. DOI: 10.4018/jmbl.2010100104.

[48] Gwo-Jen Hwang, Chin-Chung Tsai, and Stephen JH Yang. 2008. Criteria, strategies and research issues of context-aware ubiquitous learning. *Journal of Educational Technology & Society*, 11, 2.

[49] Adam Ibrahim, Brandon Huynh, Jonathan Downey, Tobias Hollerer, Dorothy Chun, and John O'donovan. 2018. ARbis pictus: a study of vocabulary learning with augmented reality. *IEEE Transactions on Visualization and Computer Graphics*, 24, 11, (Nov. 2018), 2867–2874. DOI: 10.1109/TVCG.2018.2868568.

[50] Ziwei Ji et al. 2023. Survey of hallucination in natural language generation. *ACM Computing Surveys*, 55, 12, (Dec. 31, 2023), 1–38. DOI: 10.1145/3571730.

[51] Linda C. Jones and Jan L. Plass. 2002. Supporting listening comprehension and vocabulary acquisition in french with multimedia annotations. *The Modern Language Journal*, 86, 4, (Dec. 2002), 546–561. DOI: 10.1111/1540-4781.00160.

[52] Bumsoo Kang, Chulhong Min, Wonjung Kim, Inseok Hwang, Chunjong Park, Seungchul Lee, Sung-Ju Lee, and Junehwa Song. 2017. Zaturi: we put together the 25th hour for you. create a book for your baby. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing - CSCW '17*. the 2017 ACM Conference. ACM Press, Portland, Oregon, USA, 1850–1863. ISBN: 978-1-4503-4335-0. DOI: 10.1145/2998181.2998186.

[53] Sean H. K. Kang. 2016. Spaced repetition promotes efficient and effective learning: policy implications for instruction. *Policy Insights from the Behavioral and Brain Sciences*, 3, 1, (Mar. 2016), 12–19. DOI: 10.1177/2372732215624708.

[54] Mohammed K. Khalil and Ihsan A. Elkhider. 2016. Applying learning theories and instructional design models for effective instruction. *Advances in Physiology Education*, 40, 2, (June 2016), 147–156. DOI: 10.1152/advan.00138.2015.

[55] René F. Kizilcec and Maximillian Chen. 2020. Student engagement in mobile learning via text message. In *Proceedings of the Seventh ACM Conference on Learning @ Scale*. L@S '20: Seventh (2020) ACM Conference on Learning @ Scale. ACM, Virtual Event USA, (Aug. 12, 2020), 157–166. ISBN: 978-1-4503-7951-9. DOI: 10.1145/3386527.3405921.

[56] Jeanine Krath, Linda Schürmann, and Harald F.O. von Korflesch. 2021. Revealing the theoretical basis of gamification: a systematic review and analysis of theory in research on gamification, serious games and game-based learning. *Computers in Human Behavior*, 125, (Dec. 2021), 106963. DOI: 10.1016/j.chb.2021.106963.

[57] John K. Kruschke and Torrin M. Liddell. 2018. The bayesian new statistics: hypothesis testing, estimation, meta-analysis, and power analysis from a bayesian perspective. *Psychonomic Bulletin & Review*, 25, 1, (Feb. 2018), 178–206. DOI: 10.3758/s13423-016-1221-4.

[58] Jochen Kuhn and Patrik Vogt. 2013. Smartphones as experimental tools: different methods to determine the gravitational acceleration in classroom physics by using everyday devices. *European Journal of Physics Education*, 4, 1, 16–27. Publisher: ERIC.

[59] Agnes Kukulska-Hulme and Olga Viberg. 2018. Mobile collaborative language learning: state of the art: mobile collaborative language learning. *British Journal of Educational Technology*, 49, 2, (Mar. 2018), 207–218. DOI: 10.1111/bjet.12580.

[60] Jean Lave and Etienne Wenger. 1991. *Situated learning: legitimate peripheral participation*. *Learning in doing*. Cambridge University Press, Cambridge [England] ; New York. 138 pp. ISBN: 978-0-521-42374-8.

[61] Jonathan Lazar, Jinjuan Heidi Feng, and Harry Hochheiser. 2010. *Research methods in human-computer interaction*. OCLC: ocn431936033. Wiley, Chichester, West Sussex, U.K. 426 pp. ISBN: 978-0-470-72337-1.

[62] Sangmin-Michelle Lee. 2022. A systematic review of context-aware technology use in foreign language learning. *Computer Assisted Language Learning*, 35, 3, (Mar. 4, 2022), 294–318. DOI: 10.1080/09588221.2019.1688836.

[63] Sangmin-Michelle Lee and Moonyoung Park. 2020. Reconceptualization of the context in language learning with a location-based AR app. en. *Computer Assisted Language Learning*, 33, 8, (Nov. 2020), 936–959. DOI: 10.1080/09588221.2019.1602545.

[64] Sofie M. M. Loyens, Joshua Magda, and Remy M. J. P. Rikers. 2008. Self-directed learning in problem-based learning and its relationships with self-regulated learning. *Educational Psychology Review*, 20, 4, (Dec. 2008), 411–427. DOI: 10.1007/s10648-008-9082-7.

[65] Mircea F. Lungu, Luc van den Brand, Dan Chirtoaca, and Martin Avagyan. 2018. As we may study: towards the web as a personalized language textbook. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18*. the 2018 CHI Conference. ACM Press, Montreal QC, Canada, 1–12. ISBN: 978-1-4503-5620-6. DOI: 10.1145/3173574.3173912.

[66] Qikun Ma, Shiyang Wang, Jie Liu, and Nianlong Li. 2018. InteractiveSubtitle: subtitle interaction for language learning. In *Proceedings of the Sixth International Symposium of Chinese CHI on - ChineseCHI '18*. the Sixth International Symposium of Chinese CHI. ACM Press, Montreal, QC, Canada, 116–119. ISBN: 978-1-4503-6508-6. DOI: 10.1145/3202667.3202685.

[67] R.E. Mayer. 2017. Using multimedia for e-learning. *Journal of Computer Assisted Learning*, 33, 5, (Oct. 2017), 403–423. DOI: 10.1111/jcal.12197.

[68] Richard E. Mayer, ed. The Cambridge handbook of multimedia learning. (Second Edition ed.). Cambridge Handbooks in Psychology. Cambridge University Press, New York. 930 pp. ISBN: 978-1-107-03520-1.

[69] Sharan B. Merriam. 2001. Andragogy and self-directed learning: pillars of adult learning theory. *New Directions for Adult and Continuing Education*, 2001, 89, 3. DOI: 10.1002/ace.3.

[70] Detmar Meurers, Ramon Ziai, Luiz Amaral, Adriane Boyd, Aleksandar Dimitrov, Vanessa Metcalf, and Niels Ott. 2010. Enhancing authentic web pages for language learners. In *Proceedings of the NAACL HLT 2010 Fifth Workshop on Innovative Use of NLP for Building Educational Applications*. Association for Computational Linguistics, 10–18. DOI: 10.5555/1866795.1866797.

[71] Maribel Montero Perez. 2022. Second or foreign language learning through watching audio-visual input and the role of on-screen text. en. *Language Teaching*, 55, 2, (Apr. 2022), 163–192. DOI: 10.1017/S0261444821000501.

[72] Holly Munson, Anton Yu, Ananya Rajgarhia, and AJ Noh. 2022. Introducing the new duolingo learning path. Making Duolingo. (May 6, 2022). https://blog.duolingo.com/new-duolingo-home-screen-design/.

[73] Paul Nation. 2007. The four strands. *Innovation in Language Learning and Teaching*, 1, 1, (Apr. 16, 2007), 2–13. doi: 10.2167/illt039.0.

[74] Viet Anh Nguyen, Van Cong Pham, and Si Dam Ho. 2010. A context - aware mobile learning adaptive system for supporting foreigner learning english. In *2010 IEEE RIVF International Conference on Computing & Communication Technologies, Research, Innovation, and Vision for the Future (RIVF)*. Communication Technologies, Research, Innovation, and Vision for the Future (RIVF). IEEE, Hanoi, Vietnam, (Nov. 2010), 1–6. isbn: 978-1-4244-8074-6. doi: 10.1109/RIVF.2010.5632316.

[75] Christopher P. Niemiec and Richard M. Ryan. 2009. Autonomy, competence, and relatedness in the classroom: applying self-determination theory to educational practice. *Theory and Research in Education*, 7, 2, (July 2009), 133–144. doi: 10.1177/1477878509104318.

[76] Manoela Milena Oliveira da Silva, Rafael Alves Roberto, Iulian Radu, Patricia Smith Cavalcante, and Veronica Teichrieb. 2019. Why don't we see more of augmented reality in schools? In *2019 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*. 2019 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct). IEEE, Beijing, China, (Oct. 2019), 138–143. isbn: 978-1-72814-765-9. doi: 10.1109/ISMAR-Adjunct.2019.00-61.

[77] Allan Paivio. 1969. Mental imagery in associative learning and memory. *Psychological review*, 76, 3, 241.

[78] Xuan-Lam Pham, Thi-Huyen Nguyen, Wu-Yuin Hwang, and Gwo-Dong Chen. 2016. Effects of push notifications on learner engagement in a mobile learning app. In *2016 IEEE 16th International Conference on Advanced Learning Technologies (ICALT)*. 2016 IEEE 16th International Conference on Advanced Learning Technologies (ICALT). IEEE, Austin, TX, USA, (July 2016), 90–94. isbn: 978-1-4673-9041-5. doi: 10.1109/ICALT.2016.50.

[79] Gerti Pishtari, María J. Rodríguez-Triana, Edna M. Sarmiento-Márquez, Mar Pérez-Sanagustín, Adolfo Ruiz-Calleja, Patricia Santos, Luis P. Prieto, Sergio Serrano-Iglesias, and Terje Väljataga. 2020. Learning design and learning analytics in mobile and ubiquitous learning: a systematic review. *British Journal of Educational Technology*, 51, 4, (July 2020), 1078–1100. doi: 10.1111/bjet.12944.

[80] Jan L. Plass and Shashank Pawar. 2020. Toward a taxonomy of adaptivity for learning. *Journal of Research on Technology in Education*, 52, 3, (July 2020), 275–300. doi: 10.1080/15391523.2020.1719943.

[81] Rocco Raso, Johannes Lahann, Peter Fettke, and Peter Loos. 2019. Walkable graph: an immersive augmented reality interface for performing the memory palace method. In *AMCIS 2019 Proceedings*. Twenty-fifth Americas Conference on Information Systems. Cancún.

[82] Steven Ritter, John R. Anderson, Kenneth R. Koedinger, and Albert Corbett. 2007. Cognitive tutor: applied research in mathematics education. *Psychonomic Bulletin & Review*, 14, 2, (Apr. 2007), 249–255. doi: 10.3758/BF03194060.

[83] Henry L Roediger III and Jeffrey D Karpicke. 2006. The power of testing memory: basic research and implications for educational practice. *Perspectives on Psychological Science*, 1, 3, 181–210. doi: 10.1111/j.1745-6916.2006.00012.x.

[84] Yvonne Rogers, Kay Connelly, Lenore Tedesco, William Hazlewood, Andrew Kurtz, Robert E. Hall, Josh Hursey, and Tammy Toscos. 2007. Why It's Worth the Hassle: The Value of in-Situ Studies When Designing Ubicomp. In *Proceedings of the 9th International Conference on Ubiquitous Computing* (UbiComp '07). event-place: Innsbruck, Austria. Springer-Verlag, Berlin, Heidelberg, 336–353. ISBN: 978-3-540-74852-6.

[85] Richard M. Ryan and Edward L. Deci. 2020. Intrinsic and extrinsic motivation from a self-determination theory perspective: definitions, theory, practices, and future directions. *Contemporary Educational Psychology*, 61, (Apr. 2020), 101860. DOI: 10.1016/j.cedpsych.2020.101860.

[86] Richard M. Ryan and Edward L. Deci. 2000. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, 55, 1, 68–78. DOI: 10.1037/0003-066X.55.1.68.

[87] Marc Ericson C. Santos, Arno in Wolde Lübke, Takafumi Taketomi, Goshiro Yamamoto, Ma. Mercedes T. Rodrigo, Christian Sandor, and Hirokazu Kato. 2016. Augmented reality as multimedia: the case for situated vocabulary learning. *Research and Practice in Technology Enhanced Learning*, 11, 1, (Dec. 2016). DOI: 10.1186/s41039-016-0028-2.

[88] Daniel L. Schacter. 1999. The seven sins of memory: insights from psychology and cognitive neuroscience. *American Psychologist*, 54, 3, 182–203. DOI: 10.1037/0003-066X.54.3.182.

[89] Christina Schneegass. 2021. *Embedding Mobile Learning into Everyday Settings*. PhD thesis. LMU Munich.

[90] Christina Schneegass and Fiona Draxler. 2021. Designing Task Resumption Cues for Interruptions in Mobile Learning Scenarios. en. In *Technology-Augmented Perception and Cognition*. Evangelos Niforatos and Tilman Dingler, editors. Series Title: Human–Computer Interaction Series. Springer International Publishing, Cham, 125–181. ISBN: 978-3-030-30457-7. DOI: 10.1007/978-3-030-30457-7_5.

[91] Christina Schneegass, Vincent Füseschi, Viktoriia Konevych, and Fiona Draxler. 2021. Investigating the Use of Task Resumption Cues to Support Learning in Interruption-Prone Environments. en. *Multimodal Technologies and Interaction*, 6, 1, (Dec. 2021), 2. DOI: 10.3390/mti6010002.

[92] Christina Schneegass, Thomas Kosch, Albrecht Schmidt, and Heinrich Hussmann. 2019. Investigating the potential of EEG for implicit detection of unknown words for foreign language learning. In *Human-Computer Interaction – INTERACT 2019*. Vol. 11748. David Lamas, Fernando Loizides, Lennart Nacke, Helen Petrie, Marco Winckler, and Panayiotis Zaphiris, editors. Series Title: Lecture Notes in Computer Science. Springer International Publishing, Cham, 293–313. ISBN: 978-3-030-29387-1. DOI: 10.1007/978-3-030-29387-1_17.

[93] Christina Schneegass, Nađa Terzimehić, Mariam Nettah, and Stefan Schneegass. 2018. Informing the design of user-adaptive mobile language learning applications. In *Proceedings of the 17th International Conference on Mobile and Ubiquitous Multimedia - MUM 2018*. the 17th International Conference. ACM Press, Cairo, Egypt, 233–238. ISBN: 978-1-4503-6594-9. DOI: 10.1145/3282894.3282926.

[94] Martin Schrepp, Andreas Hinderks, and Jörg Thomaschewski. 2017. Design and evaluation of a short version of the user experience questionnaire (UEQ-s). *International Journal of Interactive Multimedia and Artificial Intelligence*, 4, 6, 103. DOI: 10.9781/ijimai.2017.09.001.

[95] Dale H. Schunk. 2012. *Learning theories: an educational perspective*. (6th ed ed.). OCLC: ocn688559444. Pearson, Boston. 561 pp. ISBN: 978-0-13-707195-1.

[96] Burr Settles and Brendan Meeder. 2016. A trainable spaced repetition model for language learning. In *Proceedings of the 54th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*. Association for Computational Linguistics, Berlin, Germany, (Aug. 2016), 1848–1858. DOI: 10.18653/v1/P16-1174.

[97] Mike Sharples. 2009. Methods for evaluating mobile learning. *Researching mobile learning: Frameworks, tools and research designs*, 17–39.

[98] Mike Sharples, Josie Taylor, and Giasemi Vavoula. 2010. A theory of learning for the mobile age. In *Medienbildung in neuen Kulturräumen*. Ben Bachmair, editor. VS Verlag für Sozialwissenschaften, Wiesbaden, 87–99. ISBN: 978-3-531-92133-4. DOI: 10.1007/978-3-531-92133-4_6.

[99] Vanja Slavuj, Ana Meštrović, and Božidar Kovačić. 2017. Adaptivity in educational systems for language learning: a review. *Computer Assisted Language Learning*, 30, 1, (Feb. 17, 2017), 64–90. DOI: 10.1080/09588221.2016.1242502.

[100] Steven M. Smith and Edward Vela. 2001. Environmental context-dependent memory: a review and meta-analysis. *Psychonomic Bulletin & Review*, 8, 2, (June 2001), 203–220. DOI: 10.3758/BF03196157.

[101] John Sweller. 1994. Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction*, 4, 4, (Jan. 1994), 295–312. DOI: 10.1016/0959-4752(94)90003-5.

[102] John Sweller, Jeroen J. G. van Merriënboer, and Fred Paas. 2019. Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review*, 31, 2, (June 2019), 261–292. DOI: 10.1007/s10648-019-09465-5.

[103] Bernardo Tabuenca, Marco Kalz, Stefaan Ternier, and Marcus Specht. 2016. Mobile authoring of open educational resources for authentic learning scenarios. *Universal Access in the Information Society*, 15, 3, (Aug. 2016), 329–343. DOI: 10.1007/s10209-014-0391-y.

[104] Kelli Taylor and Doug Rohrer. 2010. The effects of interleaved practice. *Applied Cognitive Psychology*, 24, 6, (Sept. 2010), 837–848. DOI: 10.1002/acp.1598.

[105] Hendrik Thüs, Mohamed Amine Chatti, Esra Yalcin, Christoph Pallasch, Bogdan Kyryliuk, Togrul Mageramov, and Ulrik Schroeder. 2012. Mobile learning in context. en. *International Journal of Technology Enhanced Learning*, 4, 5/6, 332. DOI: 10.1504/IJTEL.2012.051818.

[106] Andrew Trusty and Khai N. Truong. 2011. Augmenting the web for second language vocabulary learning. In *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11*. the 2011 annual conference. ACM Press, Vancouver, BC, Canada, 3179. ISBN: 978-1-4503-0228-9. DOI: 10.1145/1978942.1979414.

[107] Endel Tulving. 1993. What is episodic memory? *Current Directions in Psychological Science*, 2, 3, (June 1993), 67–70. DOI: 10.1111/1467-8721.ep10770899.

[108] Endel Tulving and Donald M. Thomson. 1973. Encoding specificity and retrieval processes in episodic memory. *Psychological Review*, 80, 5, (Sept. 1973), 352–373. DOI: 10.1037/h0020071.

[109] Michael T Ullman. 2004. Contributions of memory circuits to language: the declarative/procedural model. *Cognition*, 92, 1, (May 2004), 231–270. DOI: 10.1016/j.cognition.2003.10.008.

[110] Robert Vanderplank. 2016. *Captioned Media in Foreign Language Learning and Teaching: Subtitles for the Deaf and Hard-of-Hearing as Tools for Language Learning*. Palgrave Macmillan UK, London. ISBN: 978-1-137-50045-8. DOI: 10.1057/978-1-137-50045-8.

[111] Jeroen J. G. van Merriënboer and John Sweller. 2005. Cognitive load theory and complex learning: recent developments and future directions. *Educational Psychology Review*, 17, 2, (June 2005), 147–177. DOI: 10.1007/s10648-005-3951-0.

[112] Christian David Vazquez, Afika Ayanda Nyati, Alexander Luh, Megan Fu, Takako Aikawa, and Pattie Maes. 2017. Serendipitous language learning in mixed reality. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '17*. the 2017 CHI Conference Extended Abstracts. ACM Press, Denver, Colorado, USA, 2172–2179. ISBN: 978-1-4503-4656-6. DOI: 10.1145/3027063.3053098.

[113] Venkatesh, Thong, and Xu. 2012. Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology. *MIS Quarterly*, 36, 1, 157. DOI: 10.2307/41410412.

[114] Eric-Jan Wagenmakers et al. 2018. Bayesian inference for psychology. part i: theoretical advantages and practical ramifications. *Psychonomic Bulletin & Review*, 25, 1, (Feb. 2018), 35–57. DOI: 10.3758/s13423-017-1343-3.

[115] Candace Walkington and Matthew L. Bernacki. 2020. Appraising research on personalized learning: definitions, theoretical alignment, advancements, and future directions. *Journal of Research on Technology in Education*, 52, 3, (July 2, 2020), 235–252. DOI: 10.1080/15391523.2020.1747757.

[116] Candace Walkington and Matthew L. Bernacki. 2018. Personalization of instruction: design dimensions and implications for cognition. *The Journal of Experimental Education*, 86, 1, (Jan. 2, 2018), 50–68. DOI: 10.1080/00220973.2017.1380590.

[117] Xu Wang, Srinivasa Teja Talluri, Carolyn Rose, and Kenneth Koedinger. 2019. UpGrade: sourcing student open-ended solutions to create scalable learning opportunities. In *Proceedings of the Sixth (2019) ACM Conference on Learning @ Scale*. L@S '19: Sixth (2019) ACM Conference on Learning @ Scale. ACM, Chicago IL USA, (June 24, 2019), 1–10. ISBN: 978-1-4503-6804-9. DOI: 10.1145/3330430.3333614.

[118] Yun Wen and Chee-Kit Looi. 2019. Review of augmented reality in education: situated learning with digital and non-digital resources. In *Learning in a Digital World*. Paloma Díaz, Andri Ioannou, Kaushal Kumar Bhagat, and J. Michael Spector, editors. Series Title: Smart Computing and Intelligence. Springer Singapore, Singapore, 179–193. ISBN: 978-981-13-8265-9. DOI: 10.1007/978-981-13-8265-9_9.

[119] Jacob O. Wobbrock and Julie A. Kientz. 2016. Research contributions in human-computer interaction. *Interactions*, 23, 3, (Apr. 26, 2016), 38–44. DOI: 10.1145/2907069.

[120] Shaoqun Wu, Liang Li, Ian H. Witten, and Alex Yu. 2016. Constructing a collocation learning system from the wikipedia corpus: *International Journal of Computer-Assisted Language Learning and Teaching*, 6, 3, (July 2016), 18–35. DOI: 10.4018/IJCALLT.2016070102.

[121] Fengpeng Yuan, Xianyi Gao, and Janne Lindqvist. 2017. How busy are you?: predicting the interruptibility intensity of mobile users. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*. the 2017 CHI Conference. ACM Press, Denver, Colorado, USA, 5346–5360. ISBN: 978-1-4503-4655-9. DOI: 10.1145/3025453.3025946.

[122] Lanqin Zheng, Miaolang Long, Lu Zhong, and Juliana Fosua Gyasi. 2022. The effectiveness of technology-facilitated personalized learning on learning achievements and learning perceptions: a meta-analysis. *Education and Information Technologies*, 27, 8, (Sept. 2022), 11807–11830. DOI: 10.1007/s10639-022-11092-7.

# Eidesstattliche Versicherung

(Siehe Promotionsordnung vom 12.07.11, § 8, Abs. 2 Pkt. 5)

Hiermit erkläre ich an Eides statt, dass die Dissertation von mir selbstständig, ohne unerlaubte Beihilfe angefertigt ist.

München, den 31.10.2023

Fiona Draxler