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Multimedia Learning on Mobile Phones

Does Size Matter?

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Preface

This thesis has been written as part of the two-year course *Master of Science in Learning and Teaching Technologies* (MALTT) at TECFA – a faculty of the University of Geneva to obtain a Masters degree.

Why did I embark on studying this particular topic? When I started the course at TECFA I was equipped with a simple mono-purpose mobile phone and had no idea about the use of mobile devices in education.

According to Rogers' model for the adoption and diffusion of innovations, I don't belong to the category of innovators, nor to the early adopters – who are ready to 'die', or to pay whatever it costs, to be among the first to snag a new gadget. But, as an instructional designer and content developer engaged in Higher Education, I consider it a part of my work to be informed and up to date with new trends in education; to test new technologies in real world settings; and to accumulate and improve new knowledge and skills.

'Mobile Learning' was one of these trendy new topics. After an initial hype with a flood of studies and reports accompanied by an overenthusiastic discourse, it was time to reframe the debate from my own point of view.

My first real experience of a mobile learning setting was in the historical museum of Lucerne. Since 2003 the museum have used a scanner – a kind of PDA with black and white screen – to guide the visitors through three floors filled to the roof with 3000 historical objects. Every object of the museum was identified with a bar code, which could be interpreted by using the scanner. The scanner automatically delivered written information about the object. This enabled the visitor to visit the museum at his or her own initiative or follow different 'guided' tours about a particular theme. One tour was for kids and involved a quiz. At the end, if all the questions had been answered correctly, a code was indicated on the screen of the scanner, which opened a safe and gave a prize.
The moment I saw a gaggle of kids running up and down the steps, totally engaged with their scanners, intent on their task of opening the safe, all on their own, with no adult in sight, I was convinced about the instructional and educational potential of this kind of device and curious enough to start my own investigations.

First step, I purchased a third generation cell phone – a device I would probably never have purchased otherwise: My new phone was a hybrid mixture of communication and multimedia device, incorporating many different features such as Wireless and Web Technology, enabling access to Internet and web based services. The phone was also equipped with a proper operation system designed for pocket PC mobile phones allowing the integration of third party applications – a fact that has influenced this study. I wasn't dependent on and limited to the applications preinstalled on the phone. This fact allowed me to become the architect of my own ideas and visions of mobile learning within the limited resources and capacities I had as programmer, instructional designer and researcher for this study.
To better understand the limits and possibilities of the device, I tested a range of programs and applications with respect to its instructional potential. Some of them were games programmed with Flash Lite running on a standalone player. When I saw how easy it was to run multimedia applications with Flash – a technology I was familiar with – I decided to explore the instructional potential of multimedia on mobile phones and to tackle an experimental study.

At the beginning I was very sceptical. Does everything that is technically feasible automatically make sense – particularly in an educational context where the adoption of a new technology is not just a question of lifestyle and marketing promises, but also of usefulness, efficiency, appropriateness and cost?

Multimedia phones offer a range of new applications. Technically it is possible to receive TV or to watch downloaded video clips and film material from the Internet. Some years ago Mobile TV was considered 'the next big thing'. But does it make sense and is it satisfying to watch a video produced to be broadcast on television or in the cinema, on a mobile phone screen, which is only marginally bigger than a stamp? Does a small screen automatically diminish the understanding and enjoyment of audiovisual film material? Or is that just a myth created by conservative media consumers like me, who can't imagine enjoying films anywhere other than on a huge screen in a theatre?
Every new phone has access to the Internet, allows e-mail service and the visualization of digital documents – but what does it mean to read text which is wrapped after every tenth word, and which extends several times over the screen area, so that you have to scroll at least every ten seconds?

I wanted to know whether, and in which way, these typical constraints of a mobile display affect students' learning performance. And I wanted more information about the appropriateness of different media types in a mobile setting. Are mobile screens *a priori* inferior because they are small or because the used material does not match formal requirements?

To answer these questions I carried out an experiment in which I developed four learning sequences, each containing a different dominant media type and combined them into a module. This module was tested on two different devices with respect to screen sizes: a PC screen and a mobile phone screen. The aim of this study is to gain a better understanding of the appropriate use of small-screen mobile devices to deliver multimedia learning material.

Because the scope of this thesis only allowed a pilot study, further research, experiments and tests are necessary to fully realize the potential of small-screen mobile devices. Nevertheless the results of this study enable us to make some recommendations in relation to the appropriate use of mobile devices in learning contexts. Moreover, it allows us to suggest useful directions for future research.

The learning material used for this study can be found online. The desktop material is accessible at:
http://tecfa.unige.ch/etu-maltt/linus/holdener/Memoire/LernmodulSegeln.html
The mobile version is proposed as web based emulator at:
http://tecfa.unige.ch/etu-maltt/linus/holdener/Memoire/memoire.html

Anita Holdener – August 2008

Abstract

A new generation of mobile phones incorporating more than one application into a single device has successfully entered into the telecommunications market. This category of third generation mobile phones (3G) has evolved from its primary purpose of a voice transmission device to a multimedia data device – from a functional tool to a stylish gadget, enabling information representation in various ways.
Mobile phones are small and handy – that is their strength but also their weakness. The minimizing of the screen size is probably the most obvious constraint of a mobile device affecting important aspects of the human/computer interaction.

The delivery of multimedia content on third generation mobile phones offers also new possibilities in education.
This study explores how reduced screen size and limited display capacity affects students' performance in multimedia learning. An experiment was carried out to compare the learning outcomes of 34 bachelor degree students. One half of the group was assigned a desktop computer with a 20 inch screen, the other half a multimedia mobile phone with a 2.8 inch screen. Both groups were asked to study identical test material combining four different sequences in a single learning module. Each sequence contained a different dominant media type: video, text, game and animation.

Participants of the desktop group achieved better results in terms of time, with a significant difference in the animations sequence – the most challenging part. In contrast, participants of the mobile group achieved better results in terms of scores gathered in the knowledge tests. From a total score of 80 points including the responses of all four sequences, participants of the mobile group reached on average 59 points, participants of the desktop group 50 points. This result revealed a significant difference between the two groups. Considering each sequence separately, significantly better results for participants of the mobile group could also be reported from the sequence with the text and the animations.

The thesis concludes by discussing the consequences of this result for the use of mobile devices in learning contexts and by suggesting directions for further research.

Résumé

Une nouvelle génération de téléphones portables qui contiennent plus d'une application dans un seul appareil à fait une entrée réussie dans le marché de la télécommunication.
Cette catégorie de téléphones portables de troisième génération (3G) a évolué de son rôle initial d'appareil de transmission de voix à celle d'un appareil de données multimédia, d'un outil fonctionnel à un gadget stylé qui permet la représentation d'informations de différentes manières.

Les téléphones mobiles sont de petite taille et maniable – c'est ce qui fait leur force mais aussi leur faiblesse. La petite taille de l'écran est sans doute la contrainte la plus indiscutable d'un appareil portable qui touche à d'importants aspects de l'interaction entre l'homme et la machine.

L'apport de nouvelles applications multimédia aux téléphones portables 3G offre de nouvelles possibilités éducatives.
Cette étude a été menée dans le but de voir comment un écran de taille réduite à affichage limité affecte les performances des étudiants en apprentissage multimédia. Une expérience a été menée afin de comparer les objectifs pédagogiques de 34 étudiants universitaires. La moitié du groupe a été assignée à des ordinateurs munis d'un écran de 20 pouces et l'autre moitié a utilisé des téléphones portables multimédias dotés d'un écran de 2.8 pouces. Les deux groupes ont étudié un matériel identique, soit un module de formation composé de quatre séquences distinctes. Chaque séquence contient un type de média différent: vidéo, texte, jeu et animation.

Les participants utilisant l'ordinateur ont eu de meilleurs résultats au point de vue du temps, avec une différence significative pour les séquences d'animation – la partie la plus difficile du test. À l'opposé, les participants du groupe portables, ont marqué plus de points dans les tests de connaissance. Sur un total de 80 points comprenant les réponses des quatre séquences, les participants du groupe mobiles sont arrivés à une moyenne de 59 points, les participants du groupe ordinateurs de bureau ont atteint une moyenne de 50 points. Ce résultat démontre une différence significative entre les deux groupes. Considérant chaque séquence séparément, de résultats significatifs ont été constatés parmi le groupe portable pour la séquence avec le texte et celle des animations.

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1 Introduction

The rapid growth of portable devices, in particular of mobile phones, has already caused important transformations in our everyday life providing flexible, individualistic, personal, transient and informal ways to communicate, access, manage and store information, personal data and multimedia content. Parallel to the emergence of mobile technology, there is a

> *massive growth in social media, creating a proliferation of content such as video clips, digital photos, games, podcasts and vodcasts that can be downloaded or transferred to portable devices and consumed in an out-of-home environment (Universal McCann Report, 2007, p. 2).*

This trend marks a general shift in generating content from an exclusively broadcast to a more participative user-centred era: anyone with access to the Internet can publish anything and determine what and when media data and services are accessed and used. Mobile devices perfectly support these new paradigms in atomizing and disseminating data into personalised chunks, diversified in space and time.

It is not surprising that some experts consider 'the mobile' – in particular the new generation of mobile phones – as the seventh mass media channel, beside Print, Recordings, Cinema, Radio, TV and Internet. Moore (2007) even predicts that "mobile like the Internet before it, is capable of cannibalising all of its older siblings, even devouring the Internet" (p. 10).

Mobile devices tend more and more towards convergence, reintegrating different applications and functions in an all-in-one technology. This ideal – delivering more than one application – has been realized best in a new generation of cell phones which combines into a single device the functions of: phone, camera, media player and wireless computer. Some of these multi functional third generation mobile phones have the computing power of a mid 1990s personal computer (Prensky, 2005), equipped with a particular operating system, similar software and storage memory, enabling wireless access to the Internet and the reception of multimedia services like mobile-TV. In addition they have GPR, allowing the use of location-based services and extended communication functions like MMS and VoIP.
Having all these functionalities included in one device will probably start to become the norm over the next year, and for future generations of mobile phones.

According to Universal McCann's (2007) market survey, multi-purpose cell phones are the number one most in-demand portable product, and with 2.3 billion users the mobile phone has already become the world's largest Internet, computing and communications platform.
The launch of trendy products will stimulate additional demand and 'the lifestyle they enable' (Universal McCann Report, 2007, p. 14).

What does this rapid growth of mobile technology mean for education? Are mobile devices relevant to learning, and are they a must-have technology at the beginning of a new era characterized by mobility of people and knowledge (Rheingold, 2002)?

Today, the third generation mobile phone can replicate all of the traditional media. However, observers note that “not all of it is as convenient or comfortable, but all of it is possible.” (Ahonen, Moore, 2007, http://communities-dominate.blogs.com/brands/2007/02/mobile_the_7th_.html)

The transformation from a simple communication tool to a handheld computer has enabled mobile phones to transmit and reproduce information. The dissemination of information is a primary step in dissemination of knowledge (Srivastava, 2006). According to Srivastava,

> *In any age, information, data and facts, and the process of their collection are essential to the cognitive process and to knowledge acquisition as a whole (p. 160).*

No doubt, mobile phones have the potential to be a ‘cognitive tool’ (Jonassen, 2004) and could play a role in cognitive processing. As mobile phones are able to integrate different multimedia components like text, sound, image, animation and video, we are faced with a perfect, pocket-size, multimedia learning environment that includes the interactive innovations of the personal computer.

For designers of small size and low performance multimedia, the big challenge will be to develop and choose adequate learning material that, on the one hand, match best with learners’ resources and needs, and on the other hand are appropriate and ‘media conform’.

The study aims to gather information on how the constraints and requirements of a small-screen mobile device influence multimedia learning through different media types. An experiment has been carried out to investigate the effect of two different screen size conditions on the learning performance of undergraduate students.
The results of this study should allow formulation of recommendations on how multimedia learning material should be designed and optimized to be beneficial for learning when using a small-screen mobile device.

2 Mobile Technology & Learning

2.1 Mobile Technology

In this chapter I take a closer look at *Mobile Technology* and its potential use in education in developed western countries.

The chapter is divided into four sub-chapters: The first sub-chapter defines *Mobile Technology* and relates it to a new computing paradigm. The second sub-chapter sets *Mobile Technology* in the current educational discourse and clarifies the position of the author.
The third sub-chapter contextualizes *Mobile Technology* and illustrates by means of the mobile phone as a typical exponent of *Mobile Technology* its influence on our every day life. The fourth chapter finally examines the potential of *Mobile Technology* in education.

2.1.1 Defining Mobile Technology

Mobile Technology is a novel technology. It could be seen as part of a new computing paradigm where imbedded microprocessors and the Internet were the harbingers of a transformation process leading towards an era called *Ubiquitous Computing* (Weiser, 1996).
The shrinkage of hardware components and enhanced network technology, combined with an increased demand for mobile communication, information and entertainment were the main conditions for the advent of *Mobile Technology* and the success of its applications.

A closer look at the existing terminology of *Mobile Technology* reveals a number of similar descriptions: Beside *Mobile Technology* there exist other terms like *Portable Technology*, *Handheld Technology*, *Wireless Technology* and *Ubiquitous Technology,* or *Ubiquitous Computing.* There's a great terminological inconsistency, with fluid and blurry boundaries, depending on whether a term is used in a commercial, scientific or non-professional context, for which purpose, and how long ago. The different designations are not assigned to a clear concept; rather, they describe paradigms or are characterizations of a specific range of applications and tools.

Mobile Technology forms part of *the Ubiquitous Computing* paradigm; a term invented and shaped 1996 by Mark Weiser to describe a major new trend in computing and its relationship to us. The first phase was the mainframe era, where many people shared a single computer run mostly by experts behind closed doors; and in the second phase, the *PC era*, starting in the eighties, one person had one computer. With *Ubiquitous Computing* we enter the third phase:

> *The 'UC' era will have lots of computers shared by each of us. Some of these computers will be the hundreds we may access in the course of a few minutes of Internet browsing. Others will be imbedded in walls, chairs, clothing, light switches, cars – in everything. UC is fundamentally characterized by the connection of things in the world via computation. This will take place at a many scales, including the microscopic (Weiser, 1996, http://www.ubiq.com/hypertext/weiser/acmfuture2endnote.htm).*

Mobile Technology could be situated on one of these scales Weiser mentioned. Whereas *Ubiquitous Computing* describes a visionary idea of a new relationship between computing technology and the human, *Mobile Technology* delivers, with its applications, a concrete example of this transformational process in the emerging UC era.

Mobile Technology is, precisely what the term implies – a technology that is 'mobile' – including the applications and devices built with it. These comprise a range of tools with different shapes, weights and functions designed for different purposes and customer needs e.g. mobile phone, Personal Digital Assistant (PDA), portable e-Mail device, portable media player and portable game console. All these tools can be summarized under the collective term *mobile device*.
Scientific sources disagree whether tablet PC and laptops are qualified as *mobile devices* due to their size and the time required to access and boot (Caudill, 2007). Another argument underlines that tablet PCs and laptops are not carried by people all the time, like mobile phones, and imply user experiences which are not distinct from those of a desktop computer (Livingstone, 2004). For Weiser, apart from mobility *Ubiquitous Computing* is also characterized by access to the Internet. *Mobile devices* can only be categorized as part of *Ubiquitous Computing* if they have wireless connectivity. Some definitions of *Mobile Technology* differ on this point. They also include memory sticks and mp3-players as *mobile devices*.

2.1.2 Debating Mobile Technology in Education

As this study is strongly influenced by the trend of a novel technology, I shall consider my point of view and my argument in relation to the role of technology in current educational discourse and practice. For this purpose I will start with Heidegger's sober considerations about technology.

Heidegger (1949, cited in Stassen, 2003) identified the 'essence of technology' (*Wesen der Technik*) neither in its existence nor in its form, but rather in our relationship with, and our attitude towards technology. As long as we approach technology under 'technological' aspects, we can not clearly understand it, nor use it properly:

> *We shall never experience our relationship to the essence of technology so long as we merely conceive and push forward the technological, put up with it, or evade it. Everywhere we remain unfree and chained to technology, whether we passionately affirm or deny it (p. 279).*
>
> *Wir erfahren darum niemals unsere Beziehung zum Wesen der Technik, solange wir nur das Technische vorstellen und betreiben, uns damit abfinden oder ihm ausweichen. Überall bleiben wir unfrei an die Technik gekettet, ob wir sie leidenschaftlich bejahen oder verneinen (Heidegger, 1962, p. 5).*

Every rise of a novel technology is accompanied by a lot of expectations, which lead to visionary scenarios but also to apprehension and rejection. Education is one sensitive field where such opposite and controversial positions become manifest in the theoretical discourse and practical transformation process.

A few decades ago, Marshall McLuhan (1960, cited in Nyiri, 2002) was persuaded – under the impression of the inexorable dissemination of mass media – to acknowledge a completely new situation in education:

> *Today ... most learning occurs outside the classroom. The sheer quantity of information conveyed by press-magazines-film-TV-radio far exceeds the quantity of information conveyed by school instruction and texts. This challenge has destroyed*

the monopoly of the book as a teaching aid and cracked the very walls of the classroom so suddenly that we're confused, baffled (p. 1).

The emergence of mass media channels like Radio, Film, TV and particularly Internet has, without doubt, destroyed the exclusivity of the book as learning support. Learning occurs in many informal ways outside of school. But at the same time paper/printing technologies have also evolved and kept their dominance in learning. This can be observed at every level of public education, where face-to-face discussion and paper resources still dominate (Arsham, 2002). Formal education still exists and, as may be observed in the current educational landscape after the Bologna reforms, the walls of the classroom are more solid than ever before as increasing numbers of new courses are offered.

Similarly, today a new era is proclaimed, characterized by a ubiquitous and mobile technology. The mobile phone can be seen as the most important exponent of this new era. The importance of mobile phones and other mobile devices in our everyday life and its success in a continuously growing market tempts the making of bold statements – not only by investors and exponents of the electronic and telecom industry. In education some experts herald the beginning of a new era in education.

Has *Mobile Technology* really the power to shift old paradigms of formal schooling, and be capable of "revolutionising education, transforming the traditional ways of learning and teaching into 'anytime' and particularly 'anyplace' education", like the euphoric predictions of Barker, Krull, Mallinson (2005, p. 2) and other authors of mobile learning studies?

No doubt, the mobile phone, as the most prevalent mobile device at the beginning of the mobile era, has already changed the modality of interaction and communication, and influenced our relationship to social space and time. The mobile phone is a good example of how quickly a technology has been embedded in everyday activities and become a commonplace, so unremarkable that the novelty aspect of its 'technology' has already disappeared from our consciousness.

Due to the strong presence and impact of mobile devices on our everyday life, it is not surprising that *Mobile Technology* has also influenced the educational discourse and inspired research like this.
But the optimism and enthusiasm among experts and industry for *Mobile Technology* has not reached institutions and teachers yet. "We are still far from being confident about convincing teachers," states Chan (2004, p. 16), "that adopting one-to-one TEL[1] can be effective for their teaching. It is still too complex and too distant from their immediate needs."
It is obvious that the adoption of a new technology in an institutional context is not a simple question of lifestyle. A new technology must first prove its necessity and effectiveness among established technological and pedagogical concepts. It has to find ways to institutional and governmental acceptance – processes within a complex change management that take time.

This observation leads to the assumption that a gap exists between the visions and expectations in educational theory on the one hand, and actual educational practice, on the other hand. Whereas theoretical positions in education are mostly accompanied by positive prospects, in practice a more negative attitude slows down or rejects innovative ideas. The debate about technology in education is often influenced by these two opposed positions.
A good example is the controversy about the use of mobile phones at school. In theory the fact that today, every student in industrialized countries owns a mobile phone leads automatically to the assumption that mobile phones are predestined for educational purposes; in practice mobile phones are

[1] TEL = Technology-Enhanced Learning

still regarded as ‘intruders’, as a disturbance, and therefore a disruptive technology (Mifsud, 2003). For this reason they may be banished from school and – as in some primary schools in Switzerland – strictly forbidden for use in classrooms.

Both positions – whether carried by a positive or negative attitude towards new technologies – lead finally to an impasse.

To be free of any prejudices, Heidegger (1962) suggests approaching the ‘essence’ of technology by the method of questioning. “*Wir fragen nach der Technik und möchten dadurch eine freie Beziehung zu ihr vorbereiten“* (p. 5).

As I can not go as far as Heidegger in my considerations, I propose instead an ontological approach investigating the nature of mobile devices and their role in helping people to communicate, interact and exchange with their social environment – dispositions also relevant for the process of information and knowledge acquisition.

2.1.3 Mobile like ‘Mobile Phone’

In English the word ‘mobile’ has different meanings, some of which I will analyze more closely:

- Mobile like ‘Mobile Phone’

The term ‘mobile’ has more and more become a synonym for ‘mobile phone’. It is probably the technological archetype of *Mobile Technology*.
The dream of dominating a technology, to have it under human control or, according to Heidegger’s claims, to intellectually get a grip on technology has been literally realized with the mobile phone: “*Man will, wie es heißt, die Technik ‘geistig in die Hand bekommen’. Man will sie meistern” (p. 7).* Mobile phones fit in a hand, they are ‘handy’ and easy to ‘handle’.
The ‘handiness’ and portability are main conditions for the particular relationship humans maintain with their mobile phones.

- Mobile as ‘moveable’

Mobile phones are moveable and not fixed at a particular location or space. Due to their small size they can be transported and used anywhere if the particular context does not limit their usage e.g. extreme temperatures, light conditions, invasion of the public sphere and the like.

Hulme and Truch (2005) distinguish four different spaces people normally pass through during a day: ‘working space’, ‘domestic space’ and ‘social activities’; the ‘space’ between work, home and social activities is a so called ‘*interspace’*.
The French anthropologist Marc Augé (1992) calls these anonymous and standardized places of transit ‘non-spaces’ (*non-lieux*). Under this category fall locations such as train and bus stations; airports; means of transportation as well as waiting rooms; supermarkets and big hotel chains. As a critical observer of the everyday life of a post-modern society Augé sees in ‘non-spaces’ the human reduced to a solitary individuality, to being in transition, to the provisional and the ephemeral (p. 101).

Due to their portability, mobile phones are predestined to be used in *interspaces* where people are condemned to wait anonymously. They also respond to the need to overcome moments of solitude, anonymity, non-activity and non-productivity. Mobile devices give people the opportunity to re-conquer these impersonal and unanimated spaces by extending the labour or private spaces, enabling communication and information via telephone, SMS, MMS, Internet access and web services. Thus, the boundaries between private and public, between labour and leisure, become fluid and less separate due to *Mobile Technology*. Today it has already become commonplace to make private or business phone calls in any public space.

With this rapid broadening of privacy into public eras, it is clear that institutions like Universities have to protect and defend their territory from an invasion by all kinds of private matters. During exams, for example, students have to put away their mobile phones because of the risk of cheating. Under these conditions mobile phones have a negative image and are not primarily associated with learning and teaching. In a formal school setting this is probably a big handicap for the otherwise resoundingly successful mobile phone.

Compared to calculators or laptops which are task based working instruments, mobile devices such as the mobile phone have a different status; they belong to a private sphere and are not yet considered as cognitive tools. Schools are not the only institutions that have banned the mobile phone. Cinemas, theatres, concert halls and some restaurants prohibit the use of mobile phones in some locations because they may cause disturbance.
I remember a theatre visit some years ago where the ring tone of a mobile phone interrupted an actress' performance. She was so angry about the disturbance that she started to insult the owner of the phone with the same intensity with which she had been playing the role. I only began to realize that this conversation was not part of the play when the actress turned back to the middle of the scene and couldn't find the right tone to continue her performance. The actress had been put out of her role because of a mobile phone.

This example shows that the use of *mobile devices* has its limits where the extension of privacy starts to disturb. There's also a need for public places to be protected against the invasion of private affairs, just as private spaces want to be protected against the invasion of public affairs. In the future there will still be taboo zones where the use of *mobile devices* is prohibited or where accessing the Internet is impossible. In this perspective the argument of an unlimited 'anytime' and 'anywhere' use of *mobile devices,* a mantra also uncritically repeated in many theoretical educational studies, can be identified as a pure marketing claim.

As we have seen, *mobile devices* can be transported from one place to another and carried by their owner. This condition sets the owner and his tool in a close relationship and can lead – in an extreme case – to a fusion between human and tool. The mobile phone, as a good example for this closeness, is mostly situated somewhere next to the human body in a pocket, bag or purse – a place which is very intimate and personal. In such particular cases, where devices are becoming 'personally intimate' (Alexander, 2004) a technology is more than the sum of all its functionalities: it is a part of the personality where – as in the case of the mobile phone – it will be personalized with individual ring tones, background pictures, SMS messages from friends, photos, videos, games etc.

In the eyes of Fortunati (2005), the mobile phone has even become a fetish, where activities, emotions, feelings, and fantasies are projected. This particular relationship attaches people to their tools; the emotional component is higher, more intimate and personal. Users have a more emotional relationship with their mobile phone than they do with other forms of computational device, pointed out Vincent and Harper (2003) in their study. They conclude that future services and products that satisfy emotional needs should consist of person-to-person connectivity applications which are better rated socially than person-to-information applications.

- Mobile as ‘flexible’

Mobile devices become more and more flexible, integrating more than one application in the same device and delivering a range of functions. Livingstone (2005) compares a multipurpose mobile phone with a Swiss Army Knife where it can be helpful in specific situations to perform specific tasks. As these tasks are performed mostly in a changing mobile environment the context can be identified as an important factor influencing task and goals.

> *Contexts are always determined by their specific use situation loaded with different action resources: motives, plans, other people, mobile computers, and the like (Tamminen et al. 2004, p. 136).*

When external factors such as social resources and physical environments become dynamic and unpredictable, people will manage their tasks differently from within fixed indoor contexts such as offices, classrooms or lecture halls. The intentional resources available in a dynamic environment are limited; the cognitive load to achieve a task is reduced. People have to pay constant attention to surroundings, and have to position and reposition themselves in the social context of other people and physical objects (Tamminen et al. 2004).
In such situations, people are managing different activities at the same time; it is multitasking, as they are constantly switching their foreground and background attention either to their environment, or to their activity on the mobile device. Activities done in a mobile context are characterized by a lack of continuity due to external and internal interruptions.

Ironically, the tendency to merge different applications in an all-in-one-technology reveals an opposing concept: reunifying what has been separated in the past. From this perspective, the mobile phone can be seen as a technological protest against fragmentation and specialization, smoothing the boundaries between internal and external, between space and time. However, multi purpose devices such as mobile phones are complex hybrid systems mirroring a highly media driven society, able to transport and transfer a part of its knowledge and culture in a pocket size format.

If we imagine how people interact symbiotically with their mobile phones, Clark and Chalmer's (1998) idea of the *Extended Mind* can be useful. As in their thesis about *Active Externalism,* user and mobile phone are

> *creating a coupled system that can be seen as a cognitive system in its own right. [...] If we remove the external component the system’s behavioural competence will drop, just as it would if we removed part of its brain (p. 10).*

People feel bad or react in panic when they lose or forget their mobile phones. “It has become concomitant to human existence” noted Srivastava (p. 159). When I mistakenly erased all my saved contacts and collected messages during the developing phase of this study, it was as if I had erased a ‘part of my brain’, and my radius of operability was paralyzed for a while.

- Mobile as ‘mutable’

Mobile Technology is a new technology, thus still incomplete and in a phase of development and growth. For Longo (2000, cited in Fortunati, 2007) new technologies seem like mammals, even humans: “they are born flexible and incomplete and then they develop for an indefinite length of time through interaction and learning” (p. 112).

The continued development stimulates the market with successive waves of new products and leads to a variety of different models, standards, designs and interfaces. Fortunati (2005) noticed that mobile phones are a fast changing artefact and can be considered as a modish accessory which underlies the rules of style and personal taste.
Whereas some people may be attracted by the dynamic of a permanently changing electronic market and its new products, others may be completely overstrained or their interest extinguished. There is a danger of a cleavage between two extremes: the technology advocates following and adapting quickly to new trends, and the technology deniers refusing or ignoring all kinds of market dictates.

Today the question is not whether students have mobile devices or not, but how many, which models, with which functions, and which applications, for which purpose. These are the conditions we have to deal with when we want to integrate mobile learning scenarios in concrete settings.

2.1.4 Mobile Learning – old wine in new skins?

In this chapter I would like to outline the potential, challenges and constraints of *Mobile Technology* for education, whilst keeping an eye on the existing technological and pedagogical concepts and institutional constraints in education in general, and at our University in particular.

“Every era of technology has, to some extent, formed education in its own image”, states Sharples (2003). He does not want this to be misunderstood as a “technological determinism of education” but he recognizes “that there is a mutually productive convergence between main technological influences on a culture and the contemporary educational theories and practice” (p. 1).

The influence of *Mobile Technology* on the current educational discourse can be quantified by an increasing interest and numerous publications and projects across different sectors and initiatives. With the term *Mobile Learning or M-Learning*, the trend has become its own label defining “The point at which mobile computing and e-learning intersect to produce an anytime, anywhere learning experience” (Kambourakis, Kontoni, Sapounas, 2004, p. 1). Most formal definitions relate *Mobile Learning* to E-Learning and provide a techno-centric perspective where mobile learning is primarily viewed as learning with a mobile device.

Although a young field of research, a very large number of experiments and investigations in all kinds of pedagogical directions and scientific approaches have been carried out to find out how *Mobile Learning* could be beneficial for learning. Results are very diverse. On the one hand, positive results are reported in an increasing engagement and higher motivation by the ‘coolness factor’ (Vahey, Crawford, 2003), new ways to interact (Hsi, 2003), increased cooperation and collaboration among students (Vahey, Crawford, 2003). On the other hand, the lack of ease of use due to the small screen size is still a source of dissatisfaction when used in a learning context (Waycott, Kukulska-Hulme, 2003; Jacob, Issac, 2008).

Under the impressive mass of publications with its different views and perspectives Winters (2007) deplores that *Mobile Learning* has become the victim of its own success, with a concept that is currently ill-defined. He proposes instead a re-conceptualisation of the precise nature of *Mobile Learning*. In a workshop, Winters and his colleagues tried to define some key characteristics.

Mobile Learning:

- Enables knowledge building by learners in different contexts.
- Enables learners to construct understandings.
- Mobile technology often changes the pattern of learning/work activity.
- The context of mobile learning is about more than time and space

(Winters, 2007, p. 8)

Are these findings really new or, rather old wine in new skins? After all, learning has occurred in different contexts since we can move; with the help of tools and artifacts since we can speak and hold a rattle; across different time and space in over and over changing setups and combinations since we are a part of an evolving social and cultural framework.

Low and O'Connor (2006) emphasise that *Mobile Learning* does not represent a complete new concept of learning:

> *Learning has always been mobile: we all learn as we go about our lives, with inherent dynamism and personal mobility. A book is a mobile learning resource, as is a reflective or visual process journal on paper (p. 2).*

So how does *Mobile Learning* differ from older technologies of learning and what does it contribute that is new in the educational landscape? Are there forms of pedagogy that are relevant for learning with *Mobile Technology*?

In his attempt to develop a theory of *Mobile Learning*, Sharples (2003) points out the central element of 'mobility' which distinguishes *Mobile Learning* from other types of learning activities: "It is the learner that is mobile, rather than the technology" (p. 4). He assumes that learners are continually on the move, are learning across space, time and different contexts, from topic to topic, with and without the help of technology. Sharples describes *Mobile Learning* as a 'labile activity' equal to other forms of educational activities. He postulates the inseparability of formal and informal learning and the importance of new technologies to support a mobile society where learning occurs in the interstices of daily life.

(Naithmith et al., 2004) approached theories in *Mobile Learning* from an activity-centred perspective. In their review of the literature they found six theory-based categories of activities:

Behaviourist – activities that promote learning as a change in learners observable actions. Examples: classroom response systems, assessment, content delivery by text or multimedia messages.

Constructivist – activities in which learners actively construct new ideas or concepts based on both their previous and current knowledge. Example: participatory simulations.

Situated – activities that promote learning within an authentic context and culture. Example: context-aware applications such as museum guides.

Collaborative – activities that promote learning through social interaction.
Example: online discussion boards which substitute for face-to-face discussions.

Informal and lifelong – activities that support learning outside a dedicated learning environment and formal curriculum.
Example: Access via mobile phone to trustworthy medical information.

Learning and teaching support – activities that assist in the coordination of learners and resources for learning activities.
Example: Learning organizer.
(Naithmith et al., 2004,
http://www.futurelab.org.uk/resources/publications_reports_articles/literature_reviews/Literature_Review203/)

All these specific activities and their theoretical approaches are not new and in the same manner effective for other learning and teaching situations. *Mobile Learning* is not determined by a specific learning theory and that is – like Winters (2007) pointed out – "welcomed because it leads to many possibilities for development, it poses problems when trying to develop a theory of mobile learning" (p. 7).

Taking into account these findings, a typical characteristic of *Mobile Learning* can be found in its diversity and its miscellaneous applicability. However, given the rapidly changing character of *Mobile Technology* it is difficult to formulate predictions for the future, and to develop convincing pedagogical and technological concepts which are not out of date with the launch of next generation mobile devices and the trends and new habits they enable.
Considering this, it is not surprising that the aim to develop a theory of *Mobile Learning* is a challenging undertaking.

If we focus on the current technological infrastructure and educational disposition of a small University of a developed western country, the potential for an appropriate integration of *Mobile Learning* tend to the following issues:

- Blended approach

To enable learning and teaching activities with mobile technology Naithmith et al. (2004) postulate a blended approach. They argue that successful and engaging activities are based upon different theories and practices.

- Outside of classrooms

Considering the nature of mobile devices, the most appropriate adoption of *Mobile Learning* activities will be outside of classroom where qualities such as mobility, immediacy and flexibility are needed.
In classrooms, *mobile devices* are still considered as a source of disturbance. Furthermore, they will be in competition with bigger, faster and more powerful tools: established infrastructure like desktop PCs or laptops, TV/DVD, beamer, and of course copy machines and paper.

- Built on the existing

Mobile Learning won't replace the existing. As Sharples pointed out,

> *Education in the mobile age does not replace formal education, any more than the worldwide web replaces the textbook; rather it offers a way to extend the support of learning outside of classroom (Sharples, 2005, p. 7).*

Mobile Learning could find niches or in-betweens where established technologies are too cumbersome or tend to fail and where established pedagogical methods and theoretical frameworks can not answer the demands of an increasingly mobile, media-savvy and connected society.

■ Built on the needs of a new generation of learners

Mobile Learning may address the needs of a new generation of learners who are increasingly mobile and considered as 'digital natives' (Prensky, 2001). Because this generation of learners grows up with new technology, *Mobile Learning* activities are far from new as they are familiar with the use of portable gadgets. Whilst we are still searching to develop adequate mobile learning theories, in reality, mobile devices have already become a source of socialisation – no less important than any other forms of learning in formal education.

2.2 Mobile Multimedia

In the previous chapter I tried to analyze the characteristics and particularities of *Mobile Technology* avoiding a purely technical and technological approach. It is important to regard technology as embedded in an existing context, enabling patterns of social and cultural interactions and exchange. If we do not agree with a simple technological determinism, it is more plausible to expect that *Mobile Technology* will not revolutionize our educational system. Nevertheless, it has stamped its ‘message’ by provoking or allowing subtle structural changes in our everyday life.

Mobile Technology is not only about new ways of communicating and accessing information, but also new ways of transmitting knowledge. *Mobile Multimedia* is set in this evolving process where learning is enabled in a mobile context whilst moving outside of classrooms and lecture halls. In education *Mobile Multimedia* could be defined as content represented in short multimedia units intended to support mobile learning situations and learning processes by and through mobile devices.

This study does not support or advocate a particular method or learning theory. As Kember (1997, cited in Traxler 1997) claimed, different teachers and disciplines will have different concepts of teaching. Or, with the words of Negroponte (1995, cited in Schulmeister 2002): There will never be a best solution for any given situation, because people are different and situations change. *Mobile Multimedia* fits in different contexts and learning situations, certainly, its ‘affordance’ (Latour, 1993) favours particular instructional strategies and learning theories stronger than others.

The delivery and use of *Mobile Multimedia* is probably still a minor concern among teachers. But it is undeniable that the growth in *Mobile Technology* goes side by side with a growth in social media applications such as Internet forums, sharing platforms, weblogs, wikis, podcasts etc. Some of these users and communities created material in the forms of text, images, games, podcasts and vodcasts that can be downloaded and transferred easily onto mobile devices. Beside that, commercial and non-commercial content providers are producing more and more multimedia material for mobile purposes. On the Internet there exists an increasing amount of resources for *Mobile Multimedia* ready to download and use.

Third generation mobile phones are able to store and replay a rich spectrum of such *Mobile Multimedia* content. For designers and teachers it is important to have methods to assess, choose and develop appropriate *Mobile Multimedia* units that suit best, on the one hand with learner qualification and needs, and the other hand are ‘media appropriate’. Therefore, we have to collect information about the effects on learning of different types of multimedia and different formal and aesthetical qualities. And we have to understand how the strengths and weaknesses of mobile phones determine and favour particular activities and formal aspects of information conveyance.

To answer these pertinent questions I will first develop a set of criteria to assess *Media Appropriateness* and suggest some important categories to help analyze and determine the quality of *Mobile Multimedia*. Secondly, I will evaluate theories of multimedia learning to understand the psychological impacts and “how technology – such as multimedia – can be used to foster student learning” (Mayer, Moreno, 1997, p. 1). On this base I will formulate a Multimedia Taxonomy that takes into account findings of the media appropriateness theory and cognitive multimedia learning models. The goal is to have a grid to analyze each multimedia learning sequence developed for this study under the aspect of its ‘media appropriateness’.

Finally, I will closure this chapter with an analysis of the four different media types – video, text, game and animation – used for this study.

2.2.1 Media Appropriateness

At the latest since Harold Innis (2007 [1950]) and Marshall McLuhan (1996 [1967]) identified in their media theories a causal connections between media technology and direct personal, social or cultural effects, the role of media and its influence has consistently been investigated under different views and perspectives.

In education, the discussion about media has culminated in the eighties with the question if and how media do influence learning. Clark's (1983) conclusion that "media do not influence learning under any conditions" (p. 445) and his provocative analogy that

> *media are mere vehicles that deliver instruction but do not influence student achievement any more than the truck that delivers our groceries causes changes in our nutrition (p. 445),*

has been controversially discussed. Kozma (1994) answered Clark's statement from a systemic point of view and turned over the general question from "Do media influence learning?" to a more situation-specific: "In what ways can we use the capabilities of media to influence learning for particular students, tasks, and situations?" (Kozma, 1994, p. 18).

Another paradigm – activity theory – focuses on the role of artifacts as mediators between the individual and the social environment.

> *Artifacts, broadly defined to include instruments, signs, language, and machines, mediate activity and are created by people to control their own behavior. Artifacts carry with them a particular culture and history (Kuuti, 1991) and are persistent structures that stretch across activities through time and space (Nardi, 1992, p. 75).*

Bruno Latour (1993) similarly emphasises the important aspect of mediation. In his attempt to elaborate a 'philosophy of techniques', he denounces two extreme points of view: the sociological and materialistic. While the first postulates the myth of the 'Neutral Tool' under complete human control, the latter propagates the myth of the 'Autonomous Destiny' that no human can master. Latour argues from a third position. In his eyes 'techniques' play a mediating role. It's neither the human as subject, nor the tool as object that determine the final action. Responsible for action are its 'actants' described as 'programs of action' such as goals, functions, interest, etc.
Despite the common blind spot that prevents an understanding of mediation as 'technical translation', as an exchange of properties between society and matter, Latour admits that techniques modify

> *the matter of our expression, not only its form. Techniques have meaning, but they produce meaning via a special type of articulation that crosses the common-sense boundary between signs and things (p. 38).*

If we consider the mobile phone as an 'artifact' (Fortunati, 2005) and if we assume that the role of a mobile phone is not limited to 'operational aspects of human interaction with the word' (Kaptelinin,

1996) but that mobile phones are shaping the way how people use their tools, how they communicate, interact and exchange with the reality, we have to trace and understand the ‘mediating role’ of mobile phones.

If somebody uses his mobile phone as a torch, it is probably to help him out of an emergency but in most cases it is not designated for it. The light is poor and the battery power will run out before having completed the task. It is indeed possible to use a mobile phone as a torch, but it is not a ‘media conform’ usage. If there’s a general need to use the mobile phone as a torch, the tool or the habits of the user should be adapted.
The latter case happened in a study carried out by Waycott and Kukulska-Hulme (2003) where students were asked to use a PDA for reading course material. Students’ note-taking habits were affected by the difficulty associated with entering text on the PDA. To overcome the limitations of the input capabilities and screen size, students changed their reading habits and did less note-taking and highlighting of text.
To illustrate an inappropriate use, the torch-mobile-phone analogy could be replaced by a real case from a study: Students were invited to use a handheld computer to help in organizing their studies. The handhelds were equipped with cut-down Office programs and a particular learning organizer software developed for the study. At the end, students expressed discontent about the size and weight of the handhelds which were too heavy and too large for comfortable use due to sleeve and wireless PC card accessories. The memory was reported as inadequate for holding course resources, additional PDF or media files, and any added software. Students indicated that the software ran too slowly and criticized that the content was not optimized for small screens. Another problem was the battery: left uncharged for a number of days, the handheld lost all data and programs (Sharples, Corlett, Bull, et al., 2005).

How dynamically an artifact like the mobile phone could influence and be influenced by new modes of expression and communication shows in the following example from Japan. For a young generation of Japanese the use of mobile phones has become – more than personal computers – an integral part of their lives from an early age. Some are faster to tap text with their thumbs than on a keyboard. Throughout this ‘thumb culture’ (Glotz, Bertschi, Locke, 2005) a new genre in literacy has been created: Cell Phone Novels.
The novels are mostly love stories written and consumed by young women around 20 years old. These stories are characterized by pure plot and little character development; paragraphs and sentences are kept simple and the story is often predictable (Onishi, 2008).

Without judging the quality of this new literally genre, it is interesting to see how the form – in this case the writing of text – has been determined by its technological and contextual constraints. As the cuneiform writing was the appropriate form to write on clay, the cell phone novel has become a media conform literary form for mobile phones.

These observations lead to the question: if and how mobile devices in general, and mobile phones in particular, will determine formal and aesthetical aspects of information conveyance. As Fisch (2004) noticed

> *Each medium carries its own strengths and weakness, and each presents its own constraints on the ways in which educational content can be conveyed (p. 5).*

Fisch emphasizes that these types of issues pertain to format rather than content: “Format issues grow out of the nature of users' interaction with a particular medium and the requirements/constraints in that use.” (p. 4).

As we will explore the potential of small-screen mobile devices and its particularities to convey educational content, we should consider them as a proper media in their own right, different from computers.

Kozma (1991) defines *media* by their technology, their symbol systems, and their processing capabilities. Technology means “the mechanical and electronic aspects that determine its function and to some extent its shape and other physical features” (p. 180). Therefore, the medium’s technology does define the aspects which finally have direct implications for the cognitive processes.
Salomon (1979) explored in the late 70s a so-called symbol system theory to examine how specific media interact with and impact on cognition and learning. According to this theory each medium is characterized by its ability to represent information and content via its inherent symbol system. A symbol system could be understood as sets of symbolic expressions (Kozma, 1994) in which information takes form in different types of representation, such as text, picture, sound, symbols, etc. Therefore, each representational form is ‘coded’ within a particular symbol system. “Media without symbol systems are as inconceivable as mathematics without numbers” (Salomon, p. 3).

A central problem of the mobile device is the fact that it is a novel, derivative technology, which is mostly seen as a dependent of PC and the Internet technology. As we have seen above, people are only going to discover and experiment with the implicit potential of the medium with the creation of new forms of expression and representation.
Nevertheless, mobile multimedia material is still exploited in contempt of the medium’s capacities for proper representation forms. John Denby (2007), a cinema critic of The New Yorker magazine, concludes after having watched a Hollywood film on a 2.5 inch display that

> *No exhibition method is innocent of aesthetic qualities. Platform agnosticism may flourish among kids, but platform neutrality doesn’t exist. Fifty years ago, the length of a pop single was influenced by what would fit on a forty-five-r.p.m. seven-inch disk. The length and the episodic structure of the Victorian novel — Dickens’s novels, especially — were at least partly created by writers and editors working to deadline for monthly periodicals. Television, for a variety of commercial and spatial reasons, developed the single-set or two-set sitcom. Format always affects form, and the exhibition space changes what’s exhibited* (http://www.newyorker.com/arts/critics/atlarge/2007/01/08/070108crat_atlarge_denby?currentPage=5).

Previously I used the term ‘media appropriateness’ assuming that every medium has its inherent characteristics which condition, to some extent, typical patterns of use as well as formal aspects of information conveyance.

Previous *Media Appropriateness* theories have been dominated by two main approaches: ‘social presence theory’ and ‘media richness theory’.

> *The underlying tenet of these theories is that media choice is dependent upon the characteristics of media and each communication medium is unique in its ability to convey certain information contents. [...] Therefore, these theories stipulate that media choice/appropriateness and communication effectiveness depend on properly matching the inherent characteristics of media to task requirements (King, Xia, 1999, p. 144).*

Both theories examine the relationship between media choice and task requirements assuming that individuals make a rational choice of the media that best matches their task requirements.

However, the existing *Media Appropriateness* theories have been used in work-related studies and only partly deliver a usable framework to categorize and evaluate the choice of (mobile) multimedia learning material. Therefore I will carry out an alternative way to provide a *Media Appropriateness* approach that relates formal requirements (of learning material) and media choice.

As in the current *Media Appropriateness* theories, I assume that each media is unique in its ability to convey certain information. Learning material should be chosen and represented in the light of these intrinsic characteristics. In contrast to usability studies that examine the ease-of-use of interfaces, the *Media Appropriateness* approach is more interested in the question of which formal requirements best suit a particular medium and how multimedia material should be designed to match the particularities of a target medium. On this level, *Media Appropriateness* is more a way to think about usefulness than usability.

In this study, *Media Appropriateness* does only focus on formal aspects of multimedia material. But the question could be extended and applied in a larger context to analyze whether planned tasks, activities or specific methods fit the capabilities and abilities of the chosen medium. The example cited above, where students were invited to use a handheld to organize their studies, shows that good pedagogical intentions are useless when the chosen medium is inappropriate to support learners' activities effectively.

In the next few paragraphs I will group some important evaluation categories that could help to better analyze and determine the quality of *Mobile Multimedia* learning material in terms of its ‘media appropriateness’.

- Perceived effectiveness

Is the multimedia content-medium combination an effective choice?
Is the amount of effort put into the processing of the understanding of the multimedia representation adequate, compared to the advantages delivered by the chosen medium?
In a study examining the effect of different image resolution and encoding bit rates from four different content types watched on a small screen, participants most frequently criticized the general lack of detail. A number of participants complained about visual fatigue from watching movies on a small screen. A minority also complained about the effort involved to work out what was going on when watching the small screen (Knoche, McCarthy, Sasse, 2005).
Watching movies on a small screen is not *a priori* ineffective, but formal and esthetical aspects might be adapted for small screen consumption, e.g. details and complex scenes should be avoided and the duration reduced. To overcome the lack of screen size, more attention should be attributed to auditory information. Mobile content should be optimized for effective use, avoiding unnecessary effort, fatigue and frustration.

- Designation

Has the learning material been designated for the target medium or has it been adapted from other channels, edited and modified afterwards for a second utilization or exploitation?

For cost reasons, most *Mobile Multimedia* material are only 'second hand' created and produced in view of Internet and desktop exploitation. Form and aesthetic are not adapted for a small screen, reduced memory capacity and out-of home conditions. Such inadequate material in reduced size format and compressed quality often looks like washed-out jeans that have lost their original form and colour. Denby's film experience, watching 'Pirates of the Caribbean' on a small screen, illustrates accurately such loss of quality:

> *What I saw, mainly, was a looming ship the size of a twig, patches of sparkling blue, and a face or a skull flashing by. The interiors were as dark as caves. My ears, fed by headphones, were filled with such details as the chafing of hawsers and feet stomping on straw, but there below me Johnny Depp and Orlando Bloom were duelling like two angry mosquitoes in a jar.*
> (http://www.newyorker.com/arts/critics/atlarge/2007/01/08/070108crat_atlarge_denby?currentPage=1).

Multimedia material has to be conceived at the beginning for its final media purpose; like in the design dictum 'form follows function', it should be based upon its intended designation.

- Formal compatibility

Do the formal aspects of the multimedia application generally support usability issues? In this category fall all kinds of aesthetical and formal questions about information architecture, visual design, style, duration, rhythm, font size, etc.
Is the information architecture and visual design optimized for a small screen? Is the style consistent to help the user create a mental image of the presentation?
A bad example of formal incompatibility is the use of subtitles. Subtitles may be very helpful in improving understanding when dealing with information in a foreign language.

> *But regular subtitling on mobiles doesn't work. So we're re-subtitling with slightly different wording, shorter, sharper, bigger fonts, designed to work for this particular medium. It is an example of what I said at the beginning about programming for the media, (cited in Kelly, BBC News, 2006, http://news.bbc.co.uk/1/hi/programmes/click_online/4724068.stm)*

stated Bierer from MTV in an interview, confronted with the problem of making content compelling for mobile devices.
Another example of formal incompatibility is Internet navigation on mobile phones. If websites do not provide a specific style-sheet adopted for mobile devices, urgent Internet tasks become difficult, even impossible and provoke frustration and dissatisfaction among users.

- Technical compatibility

Does the multimedia application fit into the global application architecture of the tool? Does the multimedia application support the device formats, respect the capabilities of the installed soft- and hardware, memory size, network, processing and store capacities?

- Input and Interaction ability

Does the intended interaction correspond to the abilities of the medium?
Mobile devices still have restricted input capabilities. For instance, mobile phones are not actually optimized for complex writing tasks, lacking effective ways of text input.
As the example from Japan has proved, the input restrictions could lead to new ways of expression – a potential still to be developed and examined.
Interactions in a mobile context are frequently interrupted or fragmented. Therefore complicated interaction tasks should be reduced to a minimum or designed so that they can be completed simply with one hand.

- Context compatibility

Is the multimedia material adapted to the conditions of a particular context of use?
Context is a central concern in mobile learning activities. Learning with mobile devices often takes place in physical environments that are influenced by factors as weather, light, people, noise etc. and may be far from ideal.
Multimedia content has to be represented to overcome the limitations these particular context conditions impose.

The results of such analysis can provide a first advice to the usefulness of multimedia material in a mobile setting and help identify adequate formal aspects of learning material.
The next step is to review the present approach in the light of studies in cognitive science, to better understand how the human mind works.

2.2.2 Cognitive theories of multimedia learning

One primary goal of learning is the accumulation of knowledge. Therefore, we have to understand how different representation forms assist and influence knowledge acquisition and understanding, and how information and knowledge is stored, manipulated and recalled by learners. In the past decades due to the emergence of computer assisted learning, important research has been done in the field of cognitive theories in multimedia learning.
A remaining question is: if and how these theories and their empirical studies – developed and tested during the PC era or even earlier – can be transferred to a different concept of computing, and to a new generation of learners who grew up with new technologies and therefore developed different habits and needs with regard to learning?
Schnotz (2005) emphasizes that the level of technology is important in practice, but not from a psychological point of view,

> *because comprehension is not fundamentally different when a text passage is delivered either by a computer screen or by a printed book, or if a picture is presented by a poster or by a slide. Comprehension is highly dependent on what kind of information is presented and how it is presented (p. 49).*

Let's challenge this statement later and sum up in the next paragraphs important existing theories in *Multimedia Learning*, still bearing in mind the particular conditions when learning with mobile devices.

Mayer (2005) defines *Multimedia Learning* "as learning from words (e.g., spoken or printed text) and pictures (e.g., illustration, photos, maps, graphs, animation, or video)" (p. ix).
According to Schnotz and Mayer (2005) *Multimedia Learning* is not necessary linked with high technology and is also possible with non-digital material such as books, blackboards or the use of the human voice.

The main idea of Multimedia Learning is that people learn more deeply from a combination of words and pictures than from words alone (Mayer, 2005). Mayer assumes that humans have two information processing systems – one for verbal and one for visual material. For this reason Mayer concludes that presenting material on two channels "takes advantages of the full capacity of humans for processing information." (Mayer, 2005, p. 4). Mayer's cognitive theory of multimedia learning (CTML) is based on three assumptions and their cognitive theories.

- Dual Channel Assumption

The dual channel assumption is partly rooted in the dual coding theory formulated by Paivio (1986). According to this theory the human cognition has two distinct cognitive subsystems: one system processes and stores visuo-spatial and symbolic information (pictures, nonverbal objects, events, and behaviours); the other, linguistic information (speech or writing). The two subsystems can be activated independently; but the two channels are interrelated and connected and allow the dual coding of information.

As with Paivio in his dual coding model, Baddeley (1986) supports the hypothesis that phonological and visuo-spatial information are processed in two different systems. Baddeley's model of working memory is an evolved and alternative proposition to the short-term store in Atkinson & Shiffrin's memory model (1968). This previous model explains how human memory is streamed through a linear sequence of three stages called Sensory Memory, Short Term Memory and Long Term Memory. Information is kept first by sense organs. As their ability to store information is limited, information passes into Short Term Memory, a temporary and limited storing system. Finally, in the Long Term Memory, lasting information and knowledge from minutes to a lifetime is retained.

Baddeley's basic model, which has been revised meanwhile, is based on these previous findings. His expanded working memory model is an attempt to explain how task-relevant information during the performance of a cognitive task is maintained and stored. Working memory could be seen as an interface between perception, long-term memory and action, underlying human thought processes.
Baddeley's basic model consists of three processors: coordinating central executive, which is responsible for the control and regulation of cognitive processes, and two subsystems for temporary storage of visuo-spatial and phonological based material.

Paivio's and Baddeley's models seem quite similar, but they are based on two different concepts. Whereas Paivio's model focuses on the format and whether material is presented verbally and non-verbally, Baddeley's model focuses on a sensual approach, which differentiates whether learners process the presented material through their eyes or ears. The difference between these two concepts becomes understandable when we analyze the processing of printed words. In the first model, printed words are processed in the verbal channel; in the latter, in the visual channel.
Mayer differentiates between *presentation modes* (Paivio) and *sensory modalities* (Baddeley) and makes a compromise in which he uses

> *the sensory modality approach to distinguish between visually presented material and auditory presented material as well as a presentation-mode approach to distinguish between the construction of pictorially based and verbally based models in working memory (Mayer, 2005, p. 34).*

- Limited Capacity Assumption

The limited capacity assumption takes into account the limited amount of information that can be processed in each channel at one time. Baddeley's working memory model and Sweller's (2005) cognitive load theory are examples underlying the hypothesis that the capacity and duration of working memory is limited when dealing with novel information.

G.A. Miller (1956) was the first to quantify the capacity limit of Short Term Memory by his famous formula 7+/-2 'chunks' of information. This meant that a person could only hold 5-9 chunks of information whereas a 'chunk' could refer to any meaningful unit such as words, pictures, chess positions, or people's faces.
Peterson and Peterson (1959) found that without rehearsal, information held in the Short Term Memory is quickly lost. Based on their experiment where people did retain information steadily between 3 – 18 seconds, they concluded that the duration of the Short Term Memory is limited to approximately 20 seconds.

This limited capacity forces learners to filter incoming information and apply meta-cognitive strategies to allocate cognitive resources.

- Active Processing Assumption

According to Mayer, learning is an active process in which the outcome is the construction of a coherent mental representation. (Mayer, 2005) To make sense of what is represented, a learner has to apply active cognitive processes: selecting, organizing and integrating selected material with existing knowledge (Mayer, 2005).
These processes involve the functioning of different (memory) systems. At first sight the cognitive architecture looks quite similar to the Attkinson & Shiffrin model with its division into *Sensory Memory, Working Memory* and *Long Term Memory*.

For selecting relevant material the learner needs his/her sense organs; that is, the *Sensory Memory* to bring information from the outside into the *Working Memory*. The capacity to hold information in *Sensory Memory* is limited. Therefore information will be transferred into *Working Memory,* where the learner takes his first conscious awareness of the material and then starts to organize it. The next step is the integration of selected material with prior knowledge, a process in which the learner should activate and transfer stored knowledge from the *Long Term Memory* into the *Working Memory*.
In order to help construct coherent mental representations, Mayer suggested that the presented material should have a coherent structure and provide guidance (Mayer, 2005).

■ The ITPC Model

Schnotz and Bannert (2003) have advanced the existing findings and elaborated an integrative text and picture comprehension model (ITPC) including different concepts and theories from semiotics, cognitive sciences and empirical findings in multimedia learning.
As in Paivio's dual-coding theory, they differentiate between a verbal and a pictorial channel for the processing and storage of information, but their "framework assumes that multiple representations are formed both in text comprehensions and picture comprehension" (Schnotz 2005, p. 54).
Schnotz and Bannert's framework is based on the distinction between two main forms of representation: descriptions and depictions. Whereas descriptive representations consist of symbols – abstract signs like words that have no similarity with their referent, depictive representations consist of icons – signs like pictures that are associated with their referent by similarity or structural commonality (Schnotz, 2005).
Based on this semiotic distinction between descriptive and depictive representations, they construct different mental representations for text and picture comprehension. As descriptive information is forwarded through the verbal channel and treated by the working memory to create representations, which trigger the construction or elaboration of a mental model, depictive information is forwarded by the visual channel and treated by the visual working memory directly to elaborate or construct mental models (Schnotz, 2005).
But unlike Mayer's cognitive theory of multimedia learning model (CTML) which differentiates between a verbal mental model and a pictorial mental model, Schnotz and Bannert assume that only one mental model will be constructed in gathering information from the verbal or pictorial channel.

What are the consequences of these important findings for instructional design in general, and to the design of *Mobile Multimedia*, in particular?

Based on his CTML model and the results of many empirical studies, Mayer suggests seven multimedia principles. Rebetez (2006) recapitulates it as following:

1. Multimedia principle: a message created with words and corresponding images is better retained than a message created with words alone.

2. Spatial contiguity principle: learning is improved when images and corresponding words are spatially integrated. For example, legends should be close to the corresponding picture elements.

3. Temporal contiguity principle: learning is improved when visual and verbal elements are presented together.

4. Coherence principle: learning is better when words, images and sounds not directly useful for comprehension are removed. Anecdotes, illustrations and ambient music are examples of often unnecessary elements.

5. Modality principle: animated pictures presented with an audio commentary are better understood than accompanied with on-screen text.

6. Redundancy principle: learning is better when presenting an animation with an audio commentary than an animation, its commentary, and the corresponding text.

7. Individual differences principle: these principles are stronger for learners novice in the domain; they are also stronger for learners with high visuo-spatial skills.
(Rebetez, 2006, p. 8-9)

If we take into account the typical constraints of mobile technology, characterized by limited performance, small screen and its limited ability to convey content, we see that these characteristics have similarities with the constraints of human cognitive processing with its limited working memory. The limitation of mobile devices in their low performance and small screen architecture may be a chance to reduce cognitive load.
The constraints of mobile technology oblige designers to portion information in small chunks, to be economic in the choice of verbal and visual information, precise in its design and restrained in its duration – conditions which may reduce cognitive load and facilitate active processing.

This study examines whether there is any validity to these more optimistic expectations in relation to mobile devices – its inherent limitations forces a type of design that happens to be perfect for human's limited learning capacities – or whether the more pessimistic views – mobile devices have many constraints that hamper its effectiveness as learning tools – are closer to the mark.

2.2.3 Multimedia Taxonomy

In order to identify important criteria of categorization and evaluation of multimedia material, we have to find an adequate method.

The simultaneous integration of different media types and representation forms in a unique framework for the purpose of communicating information can be thought of as *Multimedia*.
“Multimedia (MM) is a polyseme – a term with many definitions, and in this case, many roots” (Heller, 1998, p. 1).
Negroponte (1995, cited in Schulmeister 2002) reduces Multimedia to its basic components, describing it as a combination of digital data, or a mixture of bits:

> *bits co-mingle effortlessly. They start to get mixed up and can be used and reused together or separately. The mixing of audio, video, and data is called multimedia; it sounds complicated, but is nothing more than co-mingled bits (p. 18).*

Galbreath (1992, cited in Schulmeister 2002) leans in the same direction but for him multimedia is a means to an end, designed by and for humans with their sensory system: “It is a combination of hardware, software, and storage technologies incorporated to provide a multi-sensory information environment” (p. 16).

Hodges and Sasnett (1993, cited in Schulmeister 2002) emphasize the different symbolic forms of expression which are unified in a unique framework:

> *Multimedia involves more than the simple addition of new data types – simultaneous integration of a wide range of symbolic modes into a coherent framework is taking place (p. 3).*

For Mayer (2005) Multimedia is not necessarily linked with digital material, it is simply a combination of presented material in two or more forms – verbal and/or pictorial.

Due to the multifaceted character of multimedia it is important to have a common base. Therefore, I will first clarify and structure important multimedia categories with the help of existing multimedia taxonomies. The purpose is to develop a conceptual framework within mobile multimedia learning units that can be classified, and related to cognitive and media specific criteria.

The need to develop a Multimedia Taxonomy has appeared for the first time in the '70s. Bretz (1971, cited in Williams, 2002) developed a multimedia taxonomy called *Taxonomy of Communication* in which he identified sound, picture, line graphics, print and motion as different media types and showed through a series of diagrams their relationship to one other.

The lack of practicable metadata concepts with which to define important categories in multimedia applications pushed Schulmeister (2001) to draft his own *Taxonomy of Multimedia Components*. He focused particularly on interactivity and proposed a scale with six different levels of interactivity:

- Level I: Viewing objects and receiving
- Level II: Watching and receiving multiple representations
- Level III: Varying the form of representation
- Level IV: Manipulating the component content
- Level V: Constructing the object or representation contents
- Level VI: Constructing the Object or Contents of the Representation and Receiving Intelligent Feedback from the System through Manipulative Action

(Schulmeister, 2001)

Heller and Martin (Heller and Martin, 1998) first developed a Multimedia Taxonomy with the objective:

> *to analyze each individual medium for the purpose of determining storage needs, processing time, or possible cognitive load on the user, based upon the intended audience, purpose, and venue for the application (Heller, Martin, 1998, p. 5).*

Their Taxonomy was represented on two dimensions: The vertical axis described the category *Media Type*, the horizontal axis the category *Media Expression*.

Media Type contained – from up to down and related with increasing storage demands – Text, Sound, Graphics, Motion.

The horizontal scale called *Media Expression* indicated a progression from 'concrete' to 'abstract' representational forms. Heller and Martin distinguished between three types of representation: *Elaboration*, *Representation* and *Abstraction*.
Elaboration includes representational forms that are pure and unaltered. This could be untreated and low structured text, raw image and video footage. In *Representation,* the representation's form has been slightly elaborated and modified but it still keeps the character of its original. *Abstraction* means that the representation form has become abstract, for example in the form of icons.
Heller and Martin related the increasing level of abstraction to an increasing level of cognitive effort; this meant that a representational form with high abstraction would require more cognitive decoding effort than an unaltered representational form.

MEDIA TYPE	MEDIA EXPRESSION		
	Elaboration	**Representation**	**Abstraction**
TEXT	Free text, sentences, paragraphs	Bold, italics bullets, underlines, headlines, subheadings	Shapes, icons
GRAPHICS	Photograph, rendering, scanned images	Blueprint, schematic	Icon, metaphorical images
SOUND	Speech, audio transcript	Intensity, tone, inflection, sound effects	Earcon, mood music
MOTION	Raw film footage	Animation, time-lapsed photography	Animated model, highly edited video, morphed image

Figure 1: Heller and Martin's two dimensional Multimedia Taxonomy

The simplicity of Heller's and Martin's Taxonomy was helpful for a quick and rough categorization of multimedia, but it soon became inadequate when their students wanted to evaluate the quality of multimedia applications, or to examine the interaction between user and application.

Heller and Martin revisited their Multimedia Taxonomy and built a three dimensional matrix complementing the first two dimensions, *Media Type* and *Media Expression,* by a third called *Context*. This new dimension contained six discrete categories: *Audience, Discipline, Interactivity, Quality, Usefulness* and *Aesthetics*. Onto each of these categories could be attached attributes, e.g. for the category of the *Audience* this could be 'age', 'gender', 'literacy level' etc.

Another extension in their new Multimedia Taxonomy comprised the addition of a general category in the Media Expression dimension, to create an additional field for evaluative questions related to the three other categories.
As multimedia became more complex in its simultaneous integration of different multimedia forms, Heller and Martin were forced to create, in the *Media Type* dimension, a fifth category called 'Multimedia'.
Finally their new Multimedia Taxonomy was presented as follows:

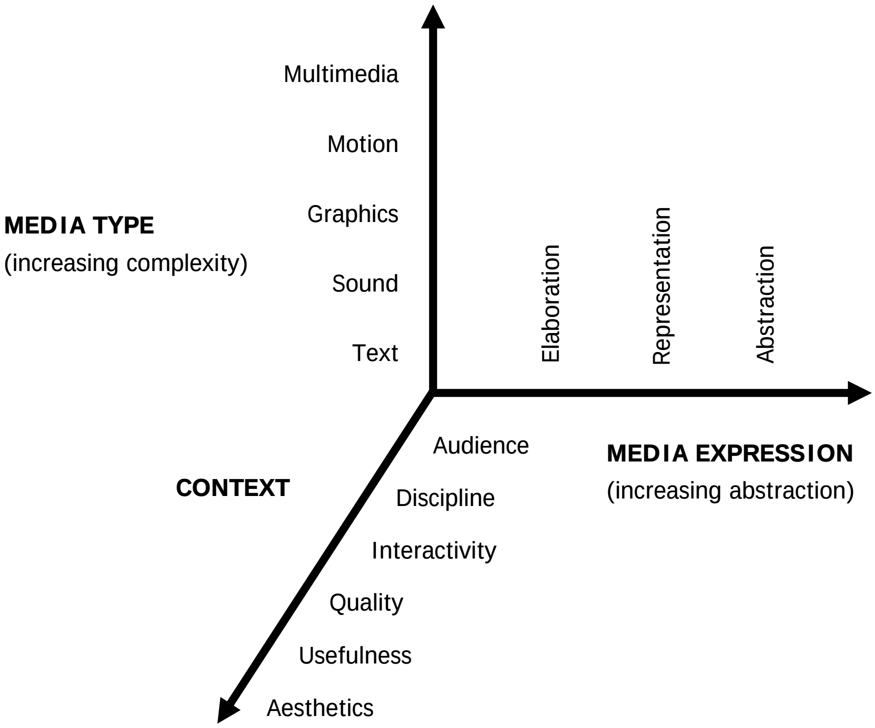


Figure 2: Heller and Martin's three dimensional matrix of Multimedia Taxonomy

2.2.4 Towards a revised Multimedia Taxonomy

Taking into account the findings of the media appropriateness approach and the cognitive theories of multimedia learning, we now have to bring together these two different concepts – on the one hand we have to consider the 'human factor', on the other hand the 'media factor' – for an integral evaluation of multimedia learning material.

Heller and Martin's two dimensional matrix with its vertical and horizontal axis serves as a starting point. This existing Multimedia Taxonomy will be analyzed, completed and revised – axis by axis and category by category.

Beginning with the vertical axis representing *Media Type*: Heller and Martin's distinction of five different *Media Types* seems from an actual point of view very limited. Multimedia has become more multifaceted, interactive and complex through new technologies and modes of expression, interaction and exchange.

The first point of contention concerns the category 'Motion'.
Heller and Martin subsumed film, video and animation into this category. From a technical point of view, film, video and animation consist of a series of frames of pictures which create an illusion of motion. But whereas the principle of film/video is to break up continuous motion into discrete frames, animation does the opposite in creating independent pictures and putting them together to form the illusion of continuous motion. Comparing animation and film/video there are also differences in how information is presented using different symbol systems. Film/videos record a series of individual images with a camera; in contrast, in animation different techniques such as drawing, graphics, modelling, or computer animation permit a diverse palette of different modes of expression.
Film/videos are mostly produced to be watched passively and in an imposed linearity; animations allow a non-linear structure and offer interactivity and exchange in the form of active participation and

manipulation of the event. For this reason the category *Motion* should be broken down into 'Film/Video' and 'Animation' to permit a more precise categorisation of motion content.

The term 'Animation' includes different definitions and meanings. To help differentiate the category *Animation* from the category *Film/Video*, I will define some criteria:

- *Computer Animation*

The category *Animation* only includes computer animations produced either with the help of computer technology and/or allow distribution and use across digital platforms.

- *Function*

Not all computer animations automatically belong to the category of *Animation*. When in doubt, animated content should be analyzed under its intended function.
According to Bétrancourt (2005) computer animation "provides a visualization of dynamic phenomenon, that are not easily observable in real space and time scales" (p. 288). Such visualizations are mostly used in scientific and educational contexts for instructional purposes. This kind of representations belongs clearly to the category of *Animation*.
In contrast, animations such as cartoons or animated films containing narrative stories are part of a specific film genre and would belong to the category *Film/Video*.

- *Interactivity*

An important feature of computer animation is its potential for different levels of interactivity – from simple control panel functions to complex manipulative actions in simulations.
Interactivity is not *per se* excluded for film/video material, but more common for computer animations.

The fifth category *Multimedia* presents another point of contention. To integrate newer forms of Multimedia such as websites, games and virtual-reality environments, the category *Multimedia* becomes too blurry and undifferentiated.
Instead of *Multimedia* three new categories have been created: Game, Hypertext and Virtual reality.

Following the top-to-down rule of increasing complexity and storage demands, the vertical axis can be represented as follows:

- Text
- Graphics
- Hypertext
- Sound
- Game
- Film/Video
- Animation
- Virtual reality

For a more precise analysis of the category *Media Type* a subcategory has been added – called *Attributes* – including the following criteria:

- Complexity
- Aesthetics
- Interaction
- Data processing
- Mental Workload

MEDIA TYPE	**ATTRIBUTES**
Text Graphics Hypertext Sound Game Film/Video Animation Virtual reality	**Complexity** duration, structure, information architecture **Aesthetics** style, representation form, colour, font type, font size, etc. **Interaction** involvement, exchange, input mode **Data processing** format, coding, bitrate, resolution, compression **Mental Workload** amount of information processing capacity and resources required to meet system demands

Figure 3: Media Type Attributes

The *Media Type Attributes* become relevant when putting the vertical axis in relation to the horizontal axis.
For this reason, let's now check the horizontal axis. Heller and Martin called it *Media Expression* containing three different levels of abstraction in order to categorize *Media Types* under its different representation forms. The level of abstraction in *Media Expression* has been linked with an increasing level of cognitive effort.

Instead of three levels of abstraction – a classification that causes problems when applying complex and hybrid multimedia material – three levels of *Media Appropriateness* has been created. The new category examines how *Media Types* fit on the one hand, with the requirements of the target medium in terms of technical compatibility and form; and on the other hand with the needs of the target learner group in terms of mental workload. Mental workload is defined as the portion of operator information processing capacity and resource required to meet system demands (O'Donnel, Eggemeier, 1986). Hence, *Media Appropriateness* include the following three levels: *Inappropriate*, *Somewhat Appropriate* and *Appropriate*.

- Inappropriate

The device does not support the media format, or the technical capacities are too limited for problem-free information processing, playback, visualisation, interaction or input.
Form and aesthetics have not been optimized for the target media.

AND / OR
Information process demands exceed mental recourses; excessive workload makes the task unmanageable for the learner or impossible to maintain an adequate performance during a while.

- Somewhat Appropriate

Information processing is technically manageable by the media platform for problem-free playback, visualisation, interaction or input.
Form and aesthetics have not been perfectly optimized for the target media.

AND

Workload is somewhat manageable by the learner; performance starts to deteriorate after a while.

- Appropriate

Information processing is technically manageable by the device for a smooth playback, visualisation, interaction or input.
Form and aesthetics are optimized for the target media.

AND

Workload is accurate; adequate performance can be maintained over long time.

The graduation within these three levels is progressive. The scale *Media Appropriateness* contains five measurements defined as *Media Type Attributes.* Each measurement reflects how the *Attributes* match on the one hand the target medium's formal and technical abilities (*Complexity*, *Aesthetics*, *Interaction*, *Data processing)*; on the other hand how strong the mental resources of the end-user in the target group are exploited by the *Media Type* and its imposed task (*Mental Workload*).
The measurements for *Complexity*, *Aesthetics*, *Interaction*, *Data processing* increase from left to right, while *Mental Workload* decreases.

As Heller and Martin pointed out, multimedia applications do not exist in a vacuum.
Two main factors, the *Target Media* and the *Target Learner Group*, were considered when analysing and assessing multimedia material implying the following questions:

- Which platform will the multimedia material be embedded on?
- Which target group will be the end-user of the multimedia application?

These two main questions could be complemented by other context relevant factors such as method, discipline, place of use, etc., depending on the focus and purpose of the evaluation.

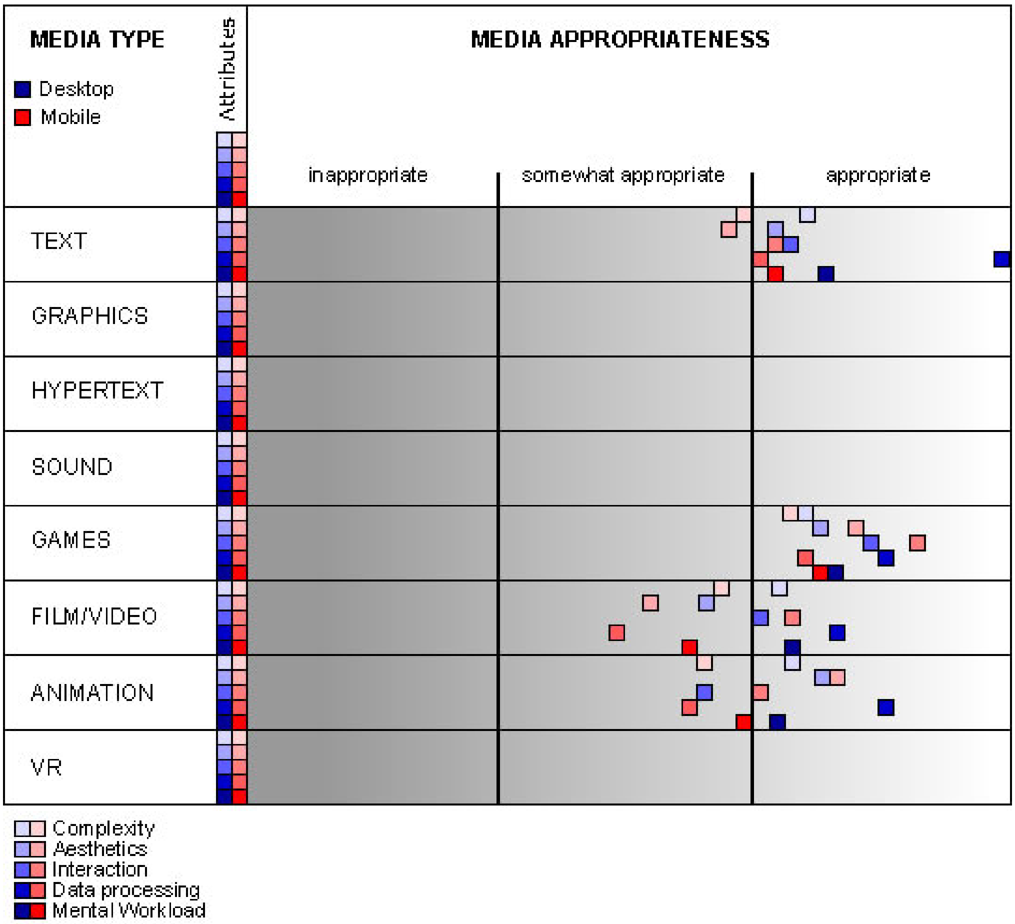


Figure 4: Assessment for the multimedia learning sequences text, game, video, animation

Figure 4 shows the assessment for the Multimedia learning sequences video, text, game and animation used for this study. The results are grouped in *Desktop Computer* and *Mobile Devise* represented by blue and red squares. Each square corresponds to an attribute defined as *Complexity, Aesthetics, Interaction, Data processing, Workload*.
The analysis above has been carried out before the experiment. The obtained results are based on objectively measurable and comparative values, as well as on personal estimations.

2.2.5 Media Types

To get an idea about the motivational clues behind the choice of my mobile learning material, I will provide for each *Media Type* used for this study (video, text, game, animation) a short analysis regarding their estimated instructional potential for an adoption on a small-screen mobile device.

- Mobile Video

"Cell phones are fast becoming the 'fourth screen' medium, after television, cinema and computers" (Sundance Institute – Press Release, 2006), declared Sundance Institute president and founder Robert Redford.
No doubt, mobile devices have become a new platform and portable exhibition space for audiovisual content: they are able to receive mobile TV programs; store and play-back videos and movies; and

offer simple features to produce and distribute instant video clips to the mobile end-user. Despite the current barriers like battery life, screen size and lack of reception, the potential for this new distribution channel has largely been recognized by national and international broadcast and film companies, as well as by commercial content providers in the field of entertainment and education.

There are different ways to provide and consume mobile video: downloaded and transferred from the computer to the storage card; streamed via web sites; video-on-demand; or via broadcast. Mobile video will not replace regular TV viewing, but supplement it, predicted Södergård (2003). And according to Denby it brings “a new convenience that will annihilate old paradigms” (http://www.newyorker.com/arts/critics/atlarge/2007/01/08/070108crat_atlarge_denby).

Mobile video isn’t necessary for good teaching. But with its proliferation, it has become an important source of additional resource material and is becoming viable as a complementary platform that can be used to disseminate knowledge in a flexible and individualistic way. Look at the increasing number of Universities offering lecture and presentation material in form of vodcasts which can be studied far from lecture halls and classrooms.
The benefits of mobile video are in choosing an adequate content in a particular setting or an adequate setting for a particular content (Chipchase et al., 2006).
In view of this potential, a video clip has been chosen for the first learning sequence of this study.

- Text

Literacy still counts as a key competence in our western society. Reading is probably, in certain domains, one of the most common activities for knowledge acquisition – independently of the media involved.

With the advancement and dissemination of information technology, powerful word-processing programs and widespread services like e-mail and the Internet, text in electronic form has challenged the supremacy of paper as the most suitable medium of text presentation and introduced new concepts of access to a world of knowledge (Dillon, 1994).
According to Salomon (Salomon 1979, cited in Reinking), printed and digital text may be distinctly different media, implying two different symbol systems and offering new situations and contexts of use. Reading text from a small mobile display is therefore different from reading a printed text.
Despite a lack of usability and the preference of most readers for printed text (Dillon, 1994) there will be situations where people will access text in electronic form via mobile device. Reading in a mobile context could imply scenarios such as checking e-mails while out of office, accessing location based information during traveling or revising before an exam or a lesson.
As I consider reading an important activity even on mobile devices, I wanted some information about the efficiency of a reading task on small-screen mobile devices.

- Game

Games in combination with mobile technology have been discovered as a fertile ground for the development of resources to support learning (Facer, et al. 2004).

> *Why are we not using digital-game based learning when overwhelming evidence provides a justification for games as a more engaging form of learning than traditional methods (p. 157)?*

asked provocatively Prensky (2001) in his book Digital Game-Based Learning. The most common argument found in the literature for using games in learning is that games are intrinsically motivating (Whitton, 2007).

The motivational aspect is one reason for the growing interest in the potential of educational games. For a use with mobile devices, another reason can be found in its appropriate conception of mobility and its perfect design for mobile platforms.
So called 'mobile casual games' – user generated games for mobile phones – are easy to pick up and play, require little commitment and a minimum of investment for players to be involved and entertained simply and immediately. They use low resources and input capacities – a simple two key input architecture is sometimes sufficient to determine win and defeat. This concept allows mobile users to fill up small amounts of time wherever they can use a mobile phone.

To test the potential of mobile games for instructional purposes, I created a mobile casual game for this study.

- Animation

Animations are closely coupled with the history of cinema, and could be seen as an established genre of visualizing complex motion sequences – remember the famous series of pictures of a horse galloping taken by the photographer Eadweard Muybridge at the end of the 19^{th} century.
Due to the powerful capacities of recent information technology, animation has evolved from a purely representative to an interactive medium – an important feature for the popularity and potential of animation in instructional design.
Despite the attractiveness and motivational benefits of animation for learning, there's no clear evidence among numerous studies that animation facilitates comprehension (Bétrancourt, 2003). Bétrancourt (2005) advises using animation only when needed and under two conditions beneficial for the learner:

> *(1) When the concept or phenomenon depicted in the animation involves change over time and it can be assumed that learners would not be able to infer the transitions between static depictions of the steps. [...] (2) When learners are novices of the domain, so they cannot form a mental model of the phenomenon or are faced with a very high cognitive load (p. 293).*

In my case the two conditions were fulfilled – first, the sailing phenomena – the topic used for this study – were quite complex and needed to be depicted in a chronological and causal relation; second, the learners were novices of the domain and had little or no prior knowledge.

2.3 Screen Size

The screen size is probably the most obvious constraint of a mobile device affecting important aspects of the human/computer interaction. The space available to display information on a mobile screen is limited; therefore, more interaction is needed in order to get the desired information, especially when the document size is much bigger than the screen size.
If we want to use mobile devices for educational purposes, we should better understand how small screens affect learning.
Nielsen (1999), as a screen size advocate, is convinced “that a bigger screen leads to better usability than a small screen” (http://www.useit.com/alertbox/991031.html). He suggests investing in large monitors because most tasks were performed faster when the user absorbed information at a single glance. (Nielsen, 2000)

Another important factor should be taken into consideration while measuring the effect of screen size: screen resolution – the amount of pixels a screen can display. Increasing screen resolution augments sharpness and clarity of an image and leads to better quality.
As Bridgeman et al. (2003) showed in their study, screen resolution can be as determinate for learning as screen size. Investigating the effect of screen size and screen resolution, they compared the learning outcome of a mathematic and verbal task of 357 high school juniors performed on 3 different screen display conditions: a 17-inch monitor set to a resolution of 1024 x 768, a 17-inch monitor set to a resolution of 640 x 480, and a simulated 15-inch monitor set to a resolution of 640 x 480.
For the verbal task, students scored better whilst using a high resolution monitor. In contrast, same resolution on different screen size showed no effect.

2.3.1 Early studies on screen size effect

The research on screen size goes back to the eighties, before the advent of the web and current proliferation of mobile devices, at a time when big screens constituted an important cost factor in computers and were expensive. This research mostly focuses on reading and comprehension under different screen size or window conditions, e.g. line length or line height.
As can be seen from the following brief review of that kind of research, the results were not conclusive and perhaps their methods differed, so they could not be compared one to one.

Some researchers found that screen size did not have a significant impact on learning outcomes. For instance, Duchnicky and Kolers (1983, cited in Richardson et al. 1989) investigated the effect of different window heights on reading constantly scrolling text, and found that there was no difference in terms of reading speed or comprehension between a text presented in the 4-line window and a text presented in the 20-line window. Similarly, Elkerton and Williges (1984, cited in Richardson et al. 1989) reported that there were few speed or accuracy advantages between the displays of 7-, 13-, and 19-line windows.

Contrary to these results, Shneiderman and Reisel (1986) reported significant effects of screen size on reading performance. In their study with the rhetorical title “Is bigger better?”, they compared four window sizes for their effectiveness in program reading. The largest window, in which the entire program was shown, had significantly better results in terms of time and score in completing the reading task. Participants also expressed a clear preference for the larger window.

Richardson et al. (1989) analyzed the effect of window size on reader comprehension and manipulation of real-word texts, and found that comprehension and performance rates were not significantly affected by screen size variations. Subjects with a small screen needed to manipulate and navigate through the text more often and spend more time on the task to comprehend it. In general participants expressed a clear preference for larger screens.

Dillon et al. (1990) reported similar results. They investigated the effects of a 20 line and a 60 line display window and splitting of sentences on readers' comprehension. Subjects were required, after reading a text of 3500 words, to summarize the main points. While the results showed that screen size had no significant effect on comprehension, the researchers reported differences in the way readers interacted with the text. Reading from the small screen led to significantly higher manipulation adjustments. Users with small screens paged forward and backward more often, and expressed the desire to change the screen size more frequently.

The results of these previous studies are very contradictory and in most cases a clear correlation between screen size, reading performance or comprehension rates could not be found. Obviously, the interaction with small screens leads to more scrolling activities. Participants expressed a clear preference for larger screens or windows.

2.3.2 Small-Screen Mobile Device

With the rapid advancement of IT technology and the cheap production of its components the focus of screen size research has escalated. Investigations on very large screens or multi-screen walls have been conducted, and, since the advent of mobile devices, numerous studies have been undertaken to understand the impact of the even smaller screens of mobile devices. Most of them have examined the impact of screen size under usability and ergonomic aspects, focusing on specific tasks such as reading, or typical services available on mobile phones like mobile Internet or more recently mobile TV. I shall briefly review some of the research on the effect of screen size in the areas of mobile reading, mobile internet and mobile video.

2.3.2.1 Mobile Reading

In their study, Waycott, J., Kukulska-Hulme (2003), evaluated the use of PDAs for reading course material. Student volunteers read three sections corresponding to 67 A4 pages of course material on a PDA. The PDA was equipped with a monochrome screen display era of 5 x 5 cm.
The main constraints and limitations identified by the students were the small screen size, navigation difficulty and the awkwardness of entering text (Waycott, J., Kukulska-Hulme, 2003). The small size and the poor quality of the screen were severely criticized. Students found it difficult to scan through text and navigate through documents; some of them felt lost. They also spent more time and needed more concentration for the reading task. In general, students found it slow and difficult to enter text on the PDA.
To overcome the limitations of the input capabilities and screen size, students did less note-taking and highlighting of text. Despite the limitations, students also found benefits in using the PDA for reading. Due to the portability and the light weight, students were able to carry course materials around in an electronic version and to access it easily in various situations.

2.3.2.2 Mobile Internet

"Any technology, no matter how bad it is, will have a few cases where people are so desperate they'll use it anyway", stated Nielsen (2000, cited in Hafner, 2000) in an interview with the New York Times some years ago, referring the stage of mobile Internet on WAP (= Wireless Applicaton Protocol) phones. Despite over-hyping and intensive design, WAP has been a failure – technically and economically, and WAP has nearly disappeared from the market. Mobile phones of the newer generation are equipped with a mini browser, but the problem with small screen Internet browsing usability is still an important concern in mobile Internet access.

Jones et al. (1999) carried out a study to explore the effects of small displays for retrieval tasks. On a web based information system developed by a worldwide financial market data provider and news service, the users were asked to complete two tasks. One group accessed the web page – originally designed for conventional, large screen displays – using a display resolution of 1074x768 pixels (approximately 30 lines); the display capacity for the second group was limited to 640x480 pixels (approximately 15 lines).
Users of the small screen were 50% less effective in completing tasks, and they evidently needed more scrolling actions in attempting to complete the tasks. 80% of small screen users felt constrained by the small screen during their task performance – compared with 40% of large screen users.
The authors noted that interface metaphors useful in a full screen desktop environment were not the most appropriate for the new devices and they suggested direct access and reduced scrolling activities for better usability of small screen Internet tasks.

Brignull (2000) approached the same problem of information retrieval under two different screen size conditions. In his study, he investigated the effect of a small screen display (240x320 pixels) on a pocket PC, and a standard large screen display (1024x768 pixels) with two different content types – one was optimized for a small screen the other for a large screen. Participants on the large screen display were significantly faster and expressed more satisfaction than those on a small screen display. Scrolling actions were also much higher with the small screen display.
The effect of representation mode (optimized content versus not optimized content) was reported as significant – but only for the small screen. Whereas under large screen conditions, users completed their tasks as quickly with non optimized content as with screen optimized content, under small screen conditions users achieved their tasks faster when content was optimized for the small screen.

Chae, M. and Kim, J. (2004) examined how information structure and screen size affect a mobile user's navigation activities and perception. In their experiment on the mobile Internet, participants had to accomplish a simple and a comparative task (single search and a comparison search). They compared the results between a six line-screen and nine-line screen as well as between three values of horizontal depth of the information structure (six levels, four levels, one level).
In the case of the complex task there was a large difference between a three-line and a six-line screen. The results showed clearly that the more complex a task grows, the more a small screen affects users' activities and perceptions.

2.3.2.3 Mobile Video

Mobile television and digital video content services have been launched by mobile phone operators and content providers around the globe. After painful failures in launching portable television in the sixties by Motorola and Sony, with the rise of multimedia mobile phones, the time was ripe for digital

Mobile TV. For some years Mobile TV has been considered a ‘the next big thing’ for mobile phones (Chipchase et al. 2005).
However, the boom in the consumer electronic industry has tended in the opposite direction, adopting giant flat screen models. “Where technology tends to shrink, television is simultaneously growing gigantic and minuscule, stretching across living room walls at the same time it slips into pockets” (Kantor, 2005). Oscillating between these two extremes, for the modern media consumer the question about the effect of screen size is a central concern.

Prior research examining the effect of screen size on attention, arousal and memory clearly reported the superiority of very large screens.

> *Viewers pay more attention to, are more aroused by, have a more intense viewing experience with, and are more likely to experience a sense of presence when consuming television content on a large screen*
> *(Kelley, 2007, p. 177).*

Kelly (2007) examined the effect of screen size and audio delivery system on absorbing facts from short television news. In his exploratory study, he compared three different size screens with two different audio delivery systems: very large screen with cabinet mounted speakers, conventional size television screen with cabinet mounted speakers, and a 2 inch small screen television with audio delivered via ear bud headphones.
On the other hand, Kelly found no statistically significant differences among the three conditions on recognition, nor on the reported viewer’s interest in the watched stories.

In their study Knoche, H., McCarthy John D., Sasse, A. (2005) focused on the impact of resolution, bit rates and content type for mobile TV. They examined the responses to four different image resolutions, seven video and two audio bit rates, and four content types. The acceptability of the perceived video quality was significantly lower when the picture size in pixels was dropped from 168x126 to 120x90, regardless of content type. The difference between the effects was more pronounced when bandwidth was abundant, and is due to important detail being lost in the smaller screens (Knoche, H., McCarthy John D., Sasse, A. 2005).

The examined cases derive from very different research foci and methods and it is difficult to find clear evidence for the superiority of big screens while watching audiovisual material.
Apparently, big screens offer a more intense, involving and emotional viewing experience than small screens, but do not influence recognition nor diminish the viewers interest or acceptability when a certain quality level of the presented material is maintained.

2.4 Problem Statement

The problem that this thesis addresses is:

What is the impact of small-screen mobile devices
a) on students' learning performance
b) their perceived cognitive load
c) their perception of the learning material?

I defined learning performance with two variables:
- Time to perform a given task in a learning sequence
- Score of correct answers or number of points (game)

The perceived cognitive load has been measured by a simplified version of the NASA-tlx test (Hart, Staveland, 1988) with three questions on a one-tenth scale:
- Effort to comprehend the message (effortless – demanding)
- Difficulty of questions (easy – difficult)
- Effort to understand interaction and use (effortless – demanding)

The perception of the learning material has been measured by four questions on a one-tenth scale:
Quality of the represented material (poor – high)
- Involvement (passive – active)
- Efficacy of the mediated content (inefficient – efficient)
- Stimulation of learning activity (low stimulation – high stimulation)

Furthermore, I wanted to know how students' learning performance is affected in multimedia learning by a small screen when using distinct media types incorporation different formal requirements. This leads me to the second problem:

How is students' learning performance affected when learning with different media types under different screen conditions?

To define media types, I developed a Multimedia Taxonomy based on Heller and Martin's theoretical Multimedia Taxonomy framework (see pages 32-39 in chapter 2.2.3 and 2.2.4 above). The new proposal examines multimedia units under two aspects:
- Media Type
- Media Appropriateness

2.4.1 Hypothesis

The theories and findings discussed in the previous chapters do not explicitly support arguments for a desktop or a small-screen mobile device use. Nevertheless, it is assumed that a familiar learning environment like a desktop computer with large screen would be more beneficial for learning:

The assessment of the multimedia learning material in terms of its 'media appropriateness' revealed in all examined cases (*Media Types*) a slight advantage for a desktop use. This means, a desktop com-

puter with a big screen would constitute the more appropriate learning environment for the chosen multimedia applications than a small-screen mobile device.
Despite a lack of conclusive results from studies examining the effect of screen size, people expressed a clear preference for large screens and they felt more comfortable while performing tasks on a large screen.

From a point of view of cognitive theories in multimedia learning, it is more difficult to find advantages for large screens as the learning material was presented nearly identical under both conditions – therefore the information was treated by the same cognitive systems. Furthermore, CTML models deny a connection between technology and learning effects as they examine learning under purely psychological aspects.
Nevertheless, it could be argued that a small screen would limit the capacity to process visually and orally presented material and augment cognitive load as users are more often distracted by usability issues like scrolling and most likely less familiar with the interaction methods on a mobile phone than on a desktop computer.

Therefore, students learning performance would be expected to be worse in term of time to complete a task and score reached in the knowledge test when using a small-screen mobile device. Cognitive load will be perceived higher when learning with a small-screen mobile device; the learning material will be perceived and estimated inferior than on a desktop screen.

- **Time**

The time taken to complete a multimedia learning sequence on a small-screen mobile device is higher than on a desktop computer.

- **Score**

Learners attain a lower score in the knowledge test working on a small-screen mobile device than on a desktop computer.

- **Perceived cognitive load**

Learners perceive a higher cognitive load with a small-screen mobile device than with a desktop computer.

- **Perception of the learning material**

Learners perceive and estimate the learning material worse on a small-screen mobile device than on a desktop computer.

3 Method

3.1 Experimental Design

The experimental design contained a multimedia learning module with four different *Media Types* – video, text, game, animation – arranged in four sequences. The material was tested on two groups, each comprising 17 participants: the *Mobile Group* (MG) used a pocket PC mobile phone with a 2.8 inch touch-screen. The *Desktop Group* (DG) used a desktop PC with a 20 inch screen, keyboard and mouse as input device.
The four sequences were presented to each group in the same order and almost identical design and layout. The only perceptible difference between the two versions was the size and the orientation. The material for the mobile setting was optimized for 240x320 pixels portrait format, the material for the desktop 640x480 pixels landscape format.

	Screen Size	**Media Type**			
		Video	Text	Game	Animation
Screen size (Between Subjects)	Mobile 2.8 inch screen	17	17	17	17
	Desktop 20 inch screen	17	17	17	17

Figure 5: Experimental design

The independent variables were *Screen Size*. The dependent variables were tracked and stored as data in a Flash shared object file:

- Start and end time of the entire module
- Start and end time of each sequence
- Duration to follow and study the instructions
- Duration for answering the questions
- Number of true answers
- Perceived cognitive load on a one-tenth scale
- Perception of the learning material on a one-tenth scale

3.1.1 Research participants

The sample for the experiment comprised 34 undergraduate students of the Economics Department at the Lucerne University of Applied Sciences and Arts. Fourteen were female and 20 male; the average age of the students was around 25 years.
All participants had no or little knowledge about sailing – the topic of the learning material – but were familiar with instructional design methods and e-learning. They also were experienced computer users; this meant at least 5 years of experience. All participants owned a mobile phone and the majority had other mobile devices in the form of mp3- or multimedia-players, game consoles or even PDAs.
All participants participated voluntarily in this study at different times of day and were remunerated at the end of the test with a bar of Swiss chocolate.

3.2 Material

The learning material was a heterogeneous multimedia module combining four different learning sequences about the topic of sailing, more precisely, the physics of sailing.[2]

Each sequence used another dominant media type, these were:

- Video
- Text in combination with a table
- Game preceded by animation/text explanations
- Animation with voice over

The duration of each sequence without questions varied between 120 and 200 seconds.
After each sequence participants had to answer a questionnaire with 7 questions regarding their perceived cognitive load and evaluation of the presented learning material followed by a knowledge test consisting of 5 - 13 questions regarding comprehension, visual or verbal recall. The module's duration was not limited and varied between 25 - 30 minutes depending on the individual tempo of the learner.

Every sequence was shown once only, and was played automatically when the user clicked on the 'continue' button of the previous page, stopping when the sequence was over. There was no way to repeat or stop the representation at any time. The user could only proceed to the next page.

The material was designed first for the pocket PC phone and was then adapted, with marginal changes in size and layout, for desktop computers. The content of the presented material was identical.
The screen resolution and the size of the interface varied between the two platforms. For the pocket PC phone the screen resolution and the material size were identical at 240x320 pixels. For the desktop version the screen resolution was set at 1600x1200 pixels, the material size was only 640x480 pixels and did not fill the entire screen. The empty space was filled with a grey border.

2 The learning material used for the desktop group can be accessed at the following link: http://tecfa.unige.ch/etu-maltt/linus/holdener/Memoire/LernmodulSegeln.html

The mobile version can be found as a web based emulator at:
http://tecfa.unige.ch/etu-maltt/linus/holdener/Memoire/memoire.html

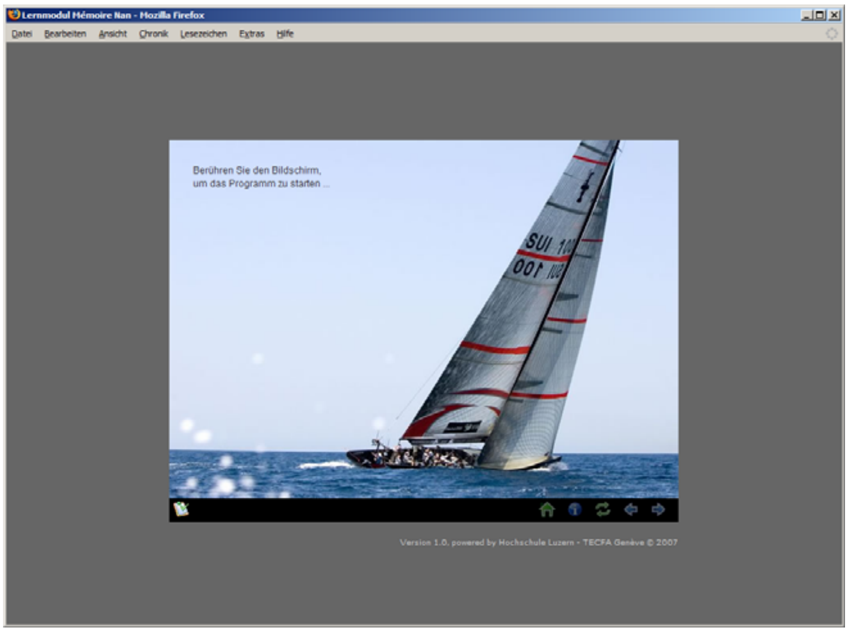


Figure 6: Disposition of learning material on mobile phone and desktop computer

While the content for the video and the text exercises was adapted from other media sources, the game and animation sequence was developed especially with regard to the small screen size in portrait format, and in respect of the limited storage and processor capacities of the mobile phone.

The order of the 4 sequences was fixed and started with the video followed by the text sequence, the game and the animations.

The topic of sailing was chosen because of the upcoming edition of the America's Cup 2007 in Valencia and its titleholder team, Alinghi. Alinghi and its Swiss captain have become national heroes and – according to some commentators – made the inhabitants of a land-locked country a proud sailing nation. Since Alinghi won the America's Cup for the first time, sailing has become very popular in Switzerland. Therefore, Alinghi and sailing made a good pretext to win students' attention for an abstract subject matter like the physics of sailing.

3.2.1 First learning sequence – video

The video clip told the history of the America's Cup in 112 seconds. The genre of the video can be defined as TV reportage, characterized by a mixture of archive film material and voice-over embedded in a linear narrative structure.
The reportage was a part of a sport program broadcast in June 2007 on the second Swiss German Channel (SF2)[3]. The video was found on the Swiss television website, streamed in Real Media.

As mobile devices are very restricted in accepting video formats, the video had to be converted and compressed to *3gp* – a multimedia container format, which is a simplified version of *MPEG-4,* developed by the 3rd Generation Partnership Project (3GPP).

[3] http://www.sf.tv/sfsport/alinghi/index.php?docid=20070621

The picture resolution of the video was 320x240 pixels. The video ran outside of the flash application, on the preinstalled media player of the device. It presented the video with a control panel to stop, forward and rewind the video; to ensure similar conditions for both groups, participants were asked not to use the panel.

The video clip for the desktop version was converted by the *Flash 8 Video Encoder* to a *Flash Video* file (flv) and then integrated in the Flash application. The resolution was set at 480x280 pixels. No control panel was made available.

The task for the learner was to watch the video once without interruption. At the end the learner had to answer eight questions – four in terms of listening comprehension, four in terms of visual recall.

	Desktop Video	**Mobile Video**
Resolution	480x280 pixels	320x240 pixels
Container Format	.flv (Flash Video)	.3GPP (3rd Generation Partnership Project)
Codec	On2 VP6	MPEG-4
Sound	MP3, mono, 48.000 kHz	AAC, mono, 32.000 kHz
File size	6.3 MB	3.9 MB
Film fps	25.00	25.00
Bit Rate	400.00 kBit/s	304.00 kBit/s
Player	Macromedia Flash Player 8.0	Windows Media Player 10 Mobile for Pocket PC

Figure 7: Technical data of video

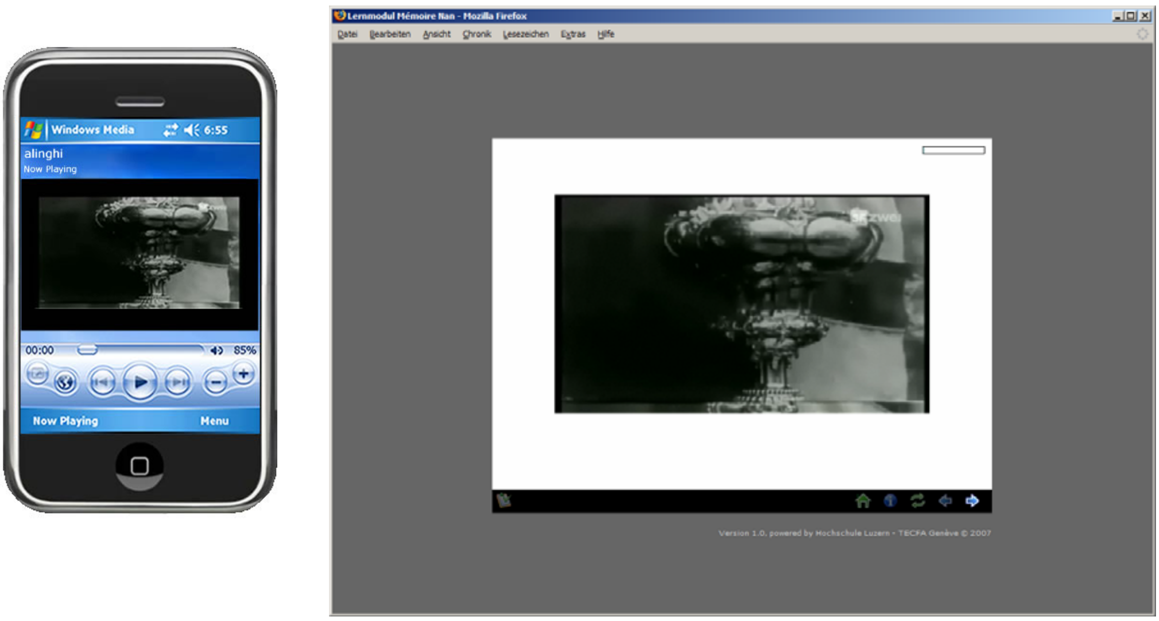


Figure 8: Disposition of the first learning sequence with the video

3.2.2 Second learning sequence – text and table

The text used in the test material was a description of the H-Boat class, the largest International keel-boat class in Europe. The information was collected from the Internet and is an amalgam of different sources. The text is complemented by an animated table giving an overview of the features of the boat, such as length, width, draft, total weight, maximum crew and an illustration of the emblem of the H-Boat class. The information on the table fades in line by line and stops when all information is displayed.

A simple reading comprehension task was carried out comprising a text with 1'543 characters. On the mobile phone the text was displayed on 57 lines, on the desktop on 34 lines divided in 6 paragraphs. In both cases, users were obliged to scroll to read the whole text. In a separate information box that popped up when the info icon was clicked, users were given six lines of explanation about a specific sailing term used in the text. The time for the activity was unlimited and participants advanced according to their desired pace.
At the end, the learner had to answer nine questions in terms of word recall (2 questions) and reading comprehension (7 questions).

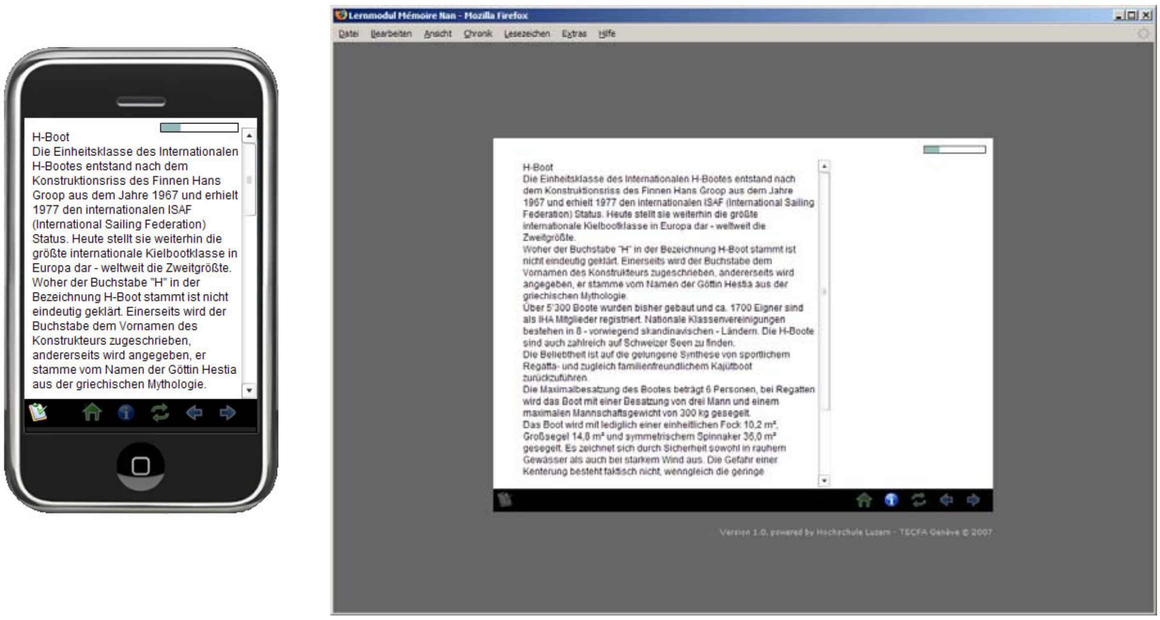


Figure 9: Disposition of the second learning sequence with text and table

3.2.3 Third learning sequence – game

The game was developed for this study and has been embedded in the third learning sequence. It was set at the end and refers to knowledge learned in the first part of the sequence. The goal of the game was to keep the sailing boat on course in relation to the direction of the wind, by setting it into one of five possible 'points of sail': *In Irons* (into the wind), *Close Hauled*, *Beam Reach*, *Broad Reach*, *Running*.
Each point of sail was presented by a short animation followed by a description. The objective of the game was to test in a playful and interactive manner what has been learnt and understood about the different points of sail.

The initial state of the game represented eight boats forming a circle. The wind direction was given. In relation to this wind direction each boat represented a different point of sail. Every 5 seconds a new point of sail was shown. The user had to click on the boat that corresponded to the right point of sail. To increase the difficulty, after ten clicks the wind direction changed randomly and the user had to imagine the point of sail in a different configuration. After having clicked 40 times, the game was over. For each true answer one point was assigned. The maximum score was 40 points.

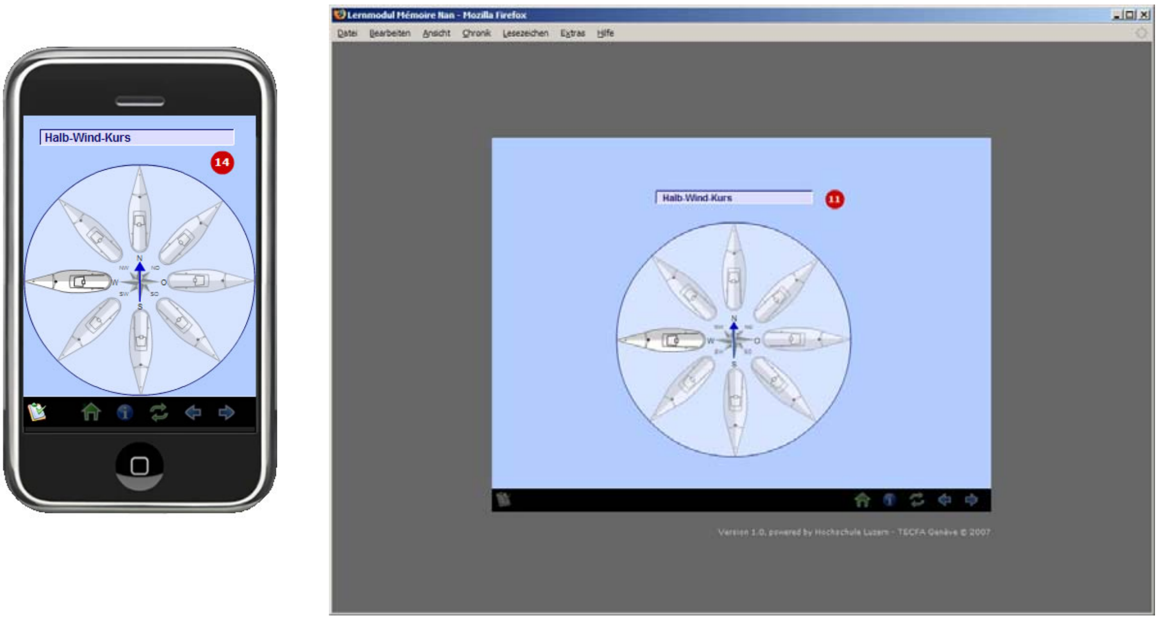


Figure 10: Disposition of the third learning sequence with game

3.2.4 Fourth learning sequence – animation

The fourth learning sequence contained four separate animations: The first two animations explained the phenomenon of the 'apparent wind' and its influence on boat speed when sailing under different sailing points. The third animation explained the 'propulsion by resistance' of a boat and the fourth animation illustrated the principle of 'propulsion by buoyancy'.

The animations conform widely to Mayer's (2005) multimedia principles. They were designed as 2-D representations, in a graphically reduced and concise style. Important areas were highlighted – in some case even enlarged. Written text was added to mark important details. All animations were accompanied by a female voice-over explaining the ongoing procedure parallel to the visual depiction.

Interactivity was limited. Bétrancourt (2005) distinguishes between two kinds of interactivity: control and interactivity. Whereas control means the capacity to control the pace and direction of animation, interactivity defines the capacity to manipulate and act directly on the configuration and parameters of animation. According to this definition there was no interactivity, only a low degree of control where the user was able to choose the pace of the succession of the animations.

At the end of the four animations the learner had to answer 13 questions of comprehension.

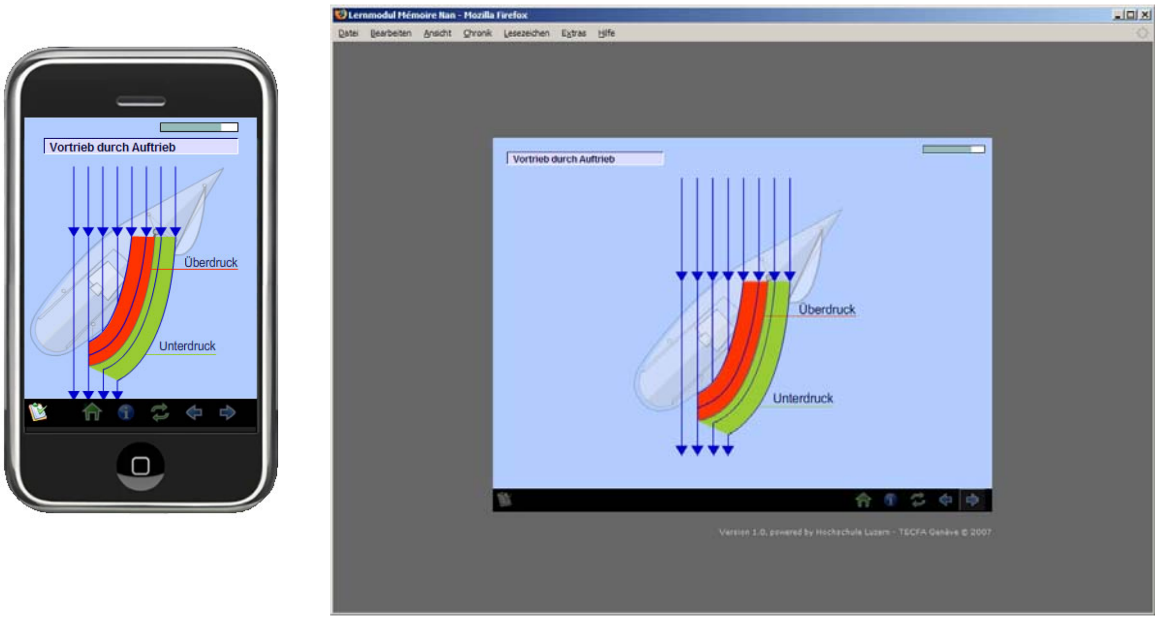


Figure 11: Disposition of the fourth learning sequence with animations

3.3 Equipment

The test material was presented on an HTC TyTN mobile phone and a Dell Pentium(R) 4CPU desktop computer. The desktop computer was equipped with a 20 inch Dell LCD flat screen, keyboard and mouse. The mobile phone had a 2.8 inch TFT-LCD screen – touch-screen and stylus serving as input device.
The following table shows an overview of the technical data of the two devices:

	Pocket PC Mobile Phone	**Desktop Computer**
Model	HTC TyTN	Dell OPTIPLEX GX 620 Pentium(R) 4CPU
Processor	400 MHz	3.00 GHz
Memory	128 MB ROM 64 MB RAM	1.00 GB RAM
Display	TFT-LCD	Dell LCD flat screen
Display size	2.8 inch	20 inch
Color depth	16 Bit	24 Bit
Screen resolution	240x320	1600x1200
Operating System	Windows Mobile 5.0 Phone Edition	Windows XP
Input devices	Touch screen with stylus Qwertz Keyboard	Keyboard Mouse
Flash Player	Flash Lite 2.1 Standalone Player	Flash Player 8 plug-in, Firefox 1.5.0.6

Figure 12: Overview technical data Pocket PC Mobile Phone – Desktop Computer

The test material was entirely programmed and designed in *Macromedia Flash 8* – and in *Flash Lite 2.0* for the mobile version. The programming language was *Action Script 2.0*.
Due to the limited processor capacity of the mobile phone, the application had to be divided into five independent parts consisting of a framework and four sequences. The framework contained the control panel and an empty 'scene' into which each sequence was loaded and played when needed.
On the mobile phone, the Flash application was running with the *Flash Lite Standalone Player 2.1;* on the desktop version, the *Flash Player 8 plug-in* with *Firefox 1.5.0.6* was used.

3.4 Procedure

The study took place between October and November 2007 in a small media room equipped with 4 desktop computers. The media room is designated only for workshops in video and multimedia. Students normally do not have access to it. Except for two students, all participants were in this room for the first time – so there were no previously associated events and feelings. All participants did the test alone on a desk in the media room – either on a mobile phone or on one of the desktop computers. The light in the room changed according to the time of day and the weather and some participants worked with artificial light. All participants were invited to use headphones during the test. It has to be noted that the headphone for the desktop computer was a High Over the Head model, the one for the mobile phone was an In Ear model.

Participants were not told the purpose of the study. At the beginning of the experiment all participants were informed that they would be guided through the program by written instructions and that the program would only permit jumping forward but not backwards. Participants knew that they would see four separate sequences about sailing and that each sequence would be showed only once.
After each sequence participants had to answer an assessment about the perceived cognitive load and the perception of the learning material. Each answer had to be expressed on a one-tenth scale moving a slider from left 1 to right 10.

Perceived cognitive load	**Perception of the learning material**
Effort to comprehend the message (effortless – demanding)	Quality of the material (poor – high)
Difficulty of questions (easy – difficult)* *This question was set after the “knowledge test”	Involvement (passive – active)
Effort to understand interaction and use (effortless – demanding)	Efficacy of the mediated content (inefficient – efficient)
	Stimulation of learning activity (low stimulation – high stimulation)

Figure 13: Assessment questions

After the assessment, which took around half a minute, a ‘knowledge test’ was presented containing between 5 and 13 questions. Participants had to answer multiple-choice questions – a combination of comprehension, visual and verbal recall questions.
Instead of multiple-choice questions, the third sequence used a game to gather information about the level of comprehension for the five points of sail learned in the first part of the sequence.
The interactivity level was – according to Schulmeisters’ (2001) taxonomy of interactivity – mostly on the lowest level. That is, in the video, text and animation sequence the user had no way of influencing the multimedia material. Only the game in sequence three allowed active interaction and exchange with the application by pointing with the stylus on the correct boat.

4 Analysis & Insights

4.1 Results

This chapter reports the results obtained by the collected data. The sample comprised 34 data sets. Levene's test of homogeneity of variance reported no significant results; this meant that the population variances were equal in all examined cases. For the analysis, the dependent variables *Time* and *Score* have been processed in a One-Way Analysis of Variance (ANOVA).
In the case of significant results, the variable *Time* has been broken down into *Instruction Time* – the duration to achieve the learning instructions – and *Response Time* – the duration to respond the knowledge test. This analysis permitted a better understanding as to whether participants spent more time on the instructional part, in viewing and studying the material, or whether they took more time to answer – or both.

4.1.1 General Findings

Students on the desktop computer were on average 138 seconds faster in performing the entire multimedia learning material. The average time for the *Desktop Group* (DG) was 26 minutes 55 seconds compared to 29 minutes 13 seconds for the *Mobile Group* (MG), nevertheless, the difference was not significant [$F(1,33)=3.868$, $MSE=162245.018$, $p=.058$].

A closer look reveals that participants in the *Mobile Group* needed both more time to study the material and more time to answer the questions during the knowledge test.
Whereas the difference of the overall *Instruction Time* between the two groups was not significant [$F(1,33)=3.329$, $MSE=103940.680$, $p=.077$], the difference of the overall *Response Time* was significant [$F(1,33)=6.390$, $MSE=6463.866$, $p<.05$].

In contrast, students using a small-screen mobile device achieved better results in the knowledge test than students using a desktop computer; surprisingly, this was the case in all four sequences and the opposite as expected in our hypothesis.
The average of total score including the results of all questions plus the game was, for the *Mobile Group* 58.88 points (max. score 80 points); the average of total score for the *Desktop Group* was 49.82 points. The results revealed a significant difference between the two groups [$F(1,33)=9.207$, $MSE=697.529$, $p<.05$].

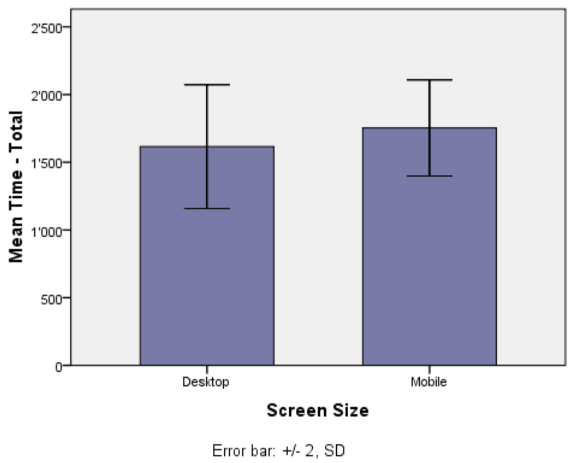


Figure 14: Mean Time - Total in Seconds

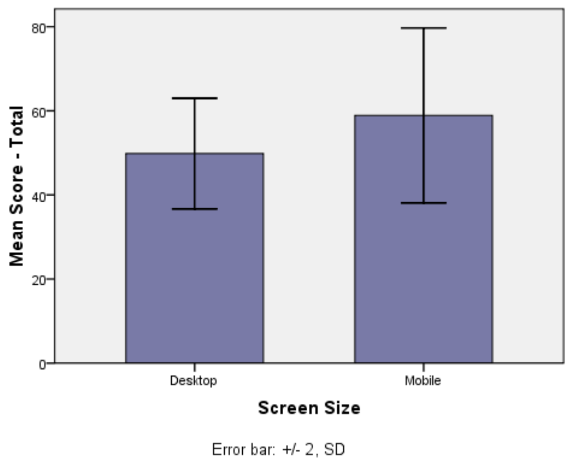


Figure 15: Mean Score - Total in Points

In general, MG participants perceived their cognitive load and evaluated the learning material quite similar to their DG colleagues. Little difference could be found on two points: MG participants estimated the level of difficulty in each sequence slightly lower and found the proposed learning content more efficient than DG participants. But in none of the examined cases the differences were significant.

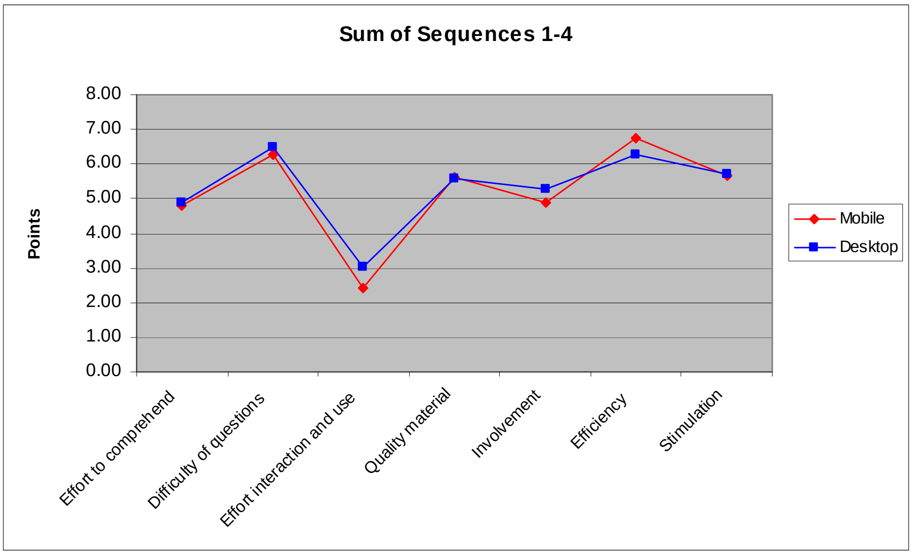


Figure 16: Mean overall perceived cognitive load and perception of learning material

To analyze if a correlation exists between the variables *Time* and *Score* and to know how the correlation varies between the four sequences, the degree of correlation has been measured. The results obtained showed no significant correlation between the examined cases.

4.1.2 Video

Participants in the *Mobile Group* needed more time to watch the video clip and to answer the questions than participants in the *Desktop Group*. However, the difference can not be reported as significant [F(1,33)=3.029, MSE=7347.354, p=.091]
It has to be noted that MG participants were slightly handicapped by technical constraints of the mobile phone: time to follow the instructions, to start and playback the video clip took in general 8 seconds more time.

Despite the lower quality of the video image and sound, the smaller screen size and the inferior technical equipment, subjects from the *Mobile Group* achieved slightly better results in the comprehension test. The mean score for the MG was 8.53 points (max. 11 points) comparing to 8.06 points for the DG. MG participants answered the four questions regarding visual recall better.
However, the difference was not significant [F(1,33)=.505, MSE=1.882 p=.482].

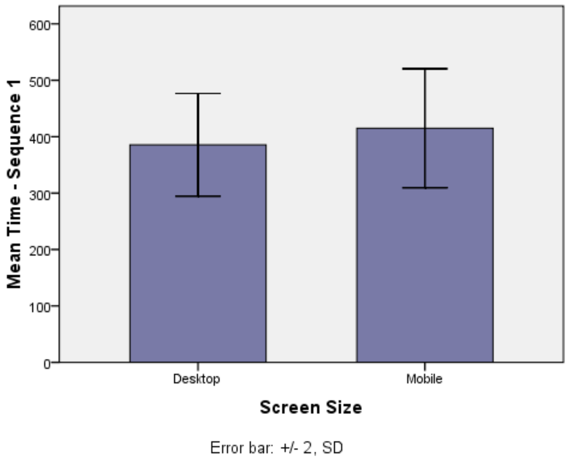


Figure 17: Mean Time - Sequence 1

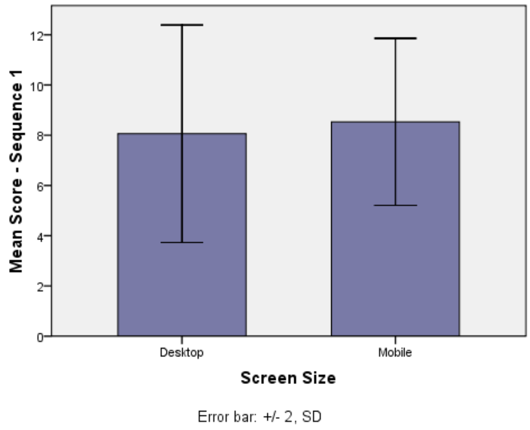


Figure 18: Mean Score - Sequence 1

Interestingly, MG participants also judged the quality of the video image better than DG participants – 6.24 against 5.41 (on a one-tenth scale). Furthermore, MG participants found it less difficult to follow the video and to navigate on the display; they also felt more actively involved, evaluated the video content more to be efficient and were more stimulated by the video presentation than their DG colleagues.

Both groups estimated the degree of difficulty of the answered questions at the same level – at 5.88.

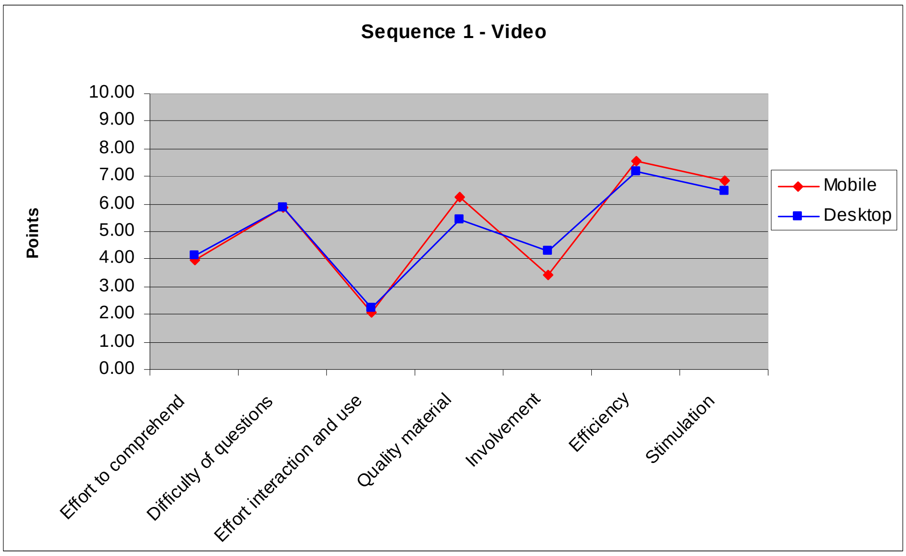


Figure 19: Mean perceived cognitive load and perception of learning material – Sequence 1

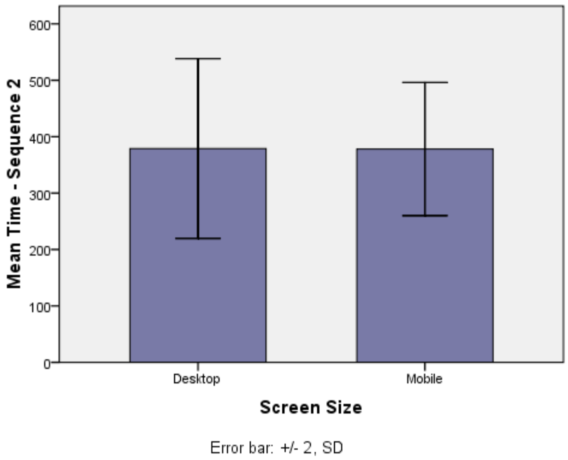
4.1.3 Text

The average time to perform the reading task and to answer nine questions was, surprisingly, lower for the *Mobile Group* than for the *Desktop Group*.

A closer look reveals that the performing time between participants varied strongly in the *Desktop Group*. Whereas the fastest subject performed the sequence in 260 seconds, the slowest did it in 550

seconds. The time for the *Mobile Group* was more homogeneous: it varied between 309 seconds for the fastest and 517 seconds for the slowest performance.
However, the result revealed no significant differences between the two groups [F(1,33)=.001, MSE=7.348, p=.969].

As in the first sequence MG members achieved better results in the knowledge test. From a total of 9 points MG members reached 7.35 points, DG members only 6.53 points. This difference between the two groups is reported as significant [F(1,33)=4.000, MSE=5.765, p<.055].



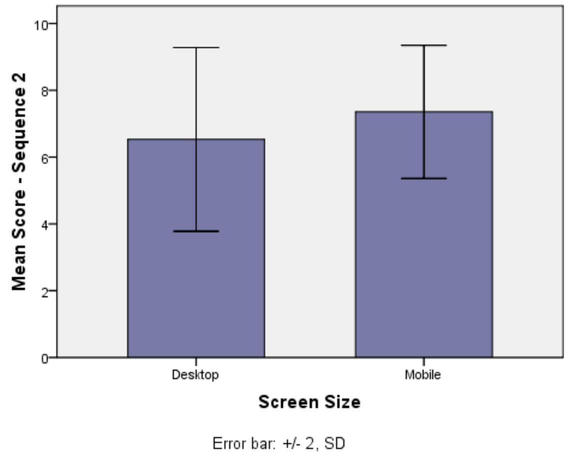


Figure 20: Mean Time - Sequence 2

Figure 21: Mean Score - Sequence 2

Participants using a high quality desktop screen judged the quality of the displayed material more severely than their colleagues with a small mobile phone screen. On the one-tenth scale the legibility (text size, wrap, paragraphs) of the text was rated by the *Desktop Group* on average at 4.53, the *Mobile Group* rated it at 6.94.

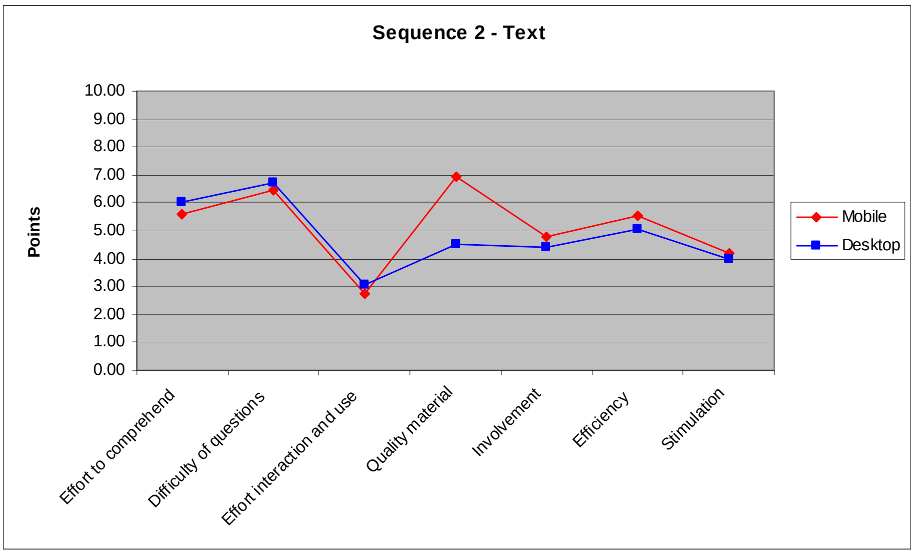


Figure 22: Mean perceived cognitive load and perception of learning material – Sequence 2

4.1.4 Game

In the game sequence the *Desktop Group* performed better in terms of time than their colleagues in the *Mobile Group*, but the difference could not be reported as significant [F(1,33)=2.297, MSE=16451.732, p=.139]. On average, the MG spent 44 seconds more in studying the learning material and in playing the game than the DG.

In contrast, MG participants collected more points in the game than participants from the control group. From a total of 40 points, the MG achieved 29 point compared to 24 points for the DG – nevertheless the result was not significant [F(1,33)=3.410, MSE=212.500, p=.074].

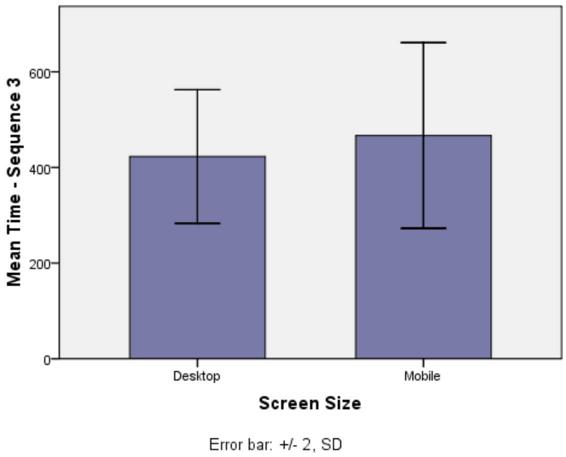


Figure 23: Mean Time - Sequence 3

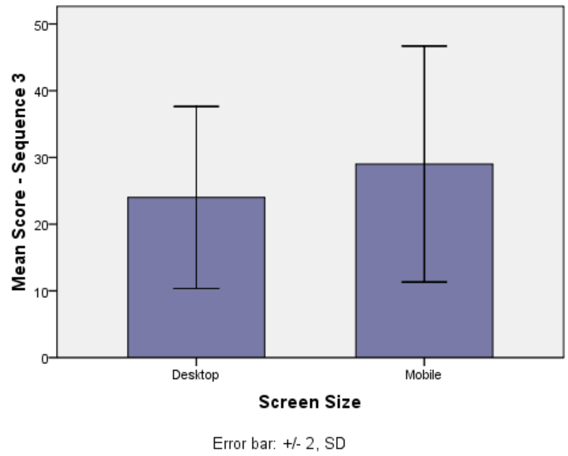


Figure 24: Mean Score - Sequence 3

Participants of both groups estimated their perceived cognitive load and the learning material quite similarly.

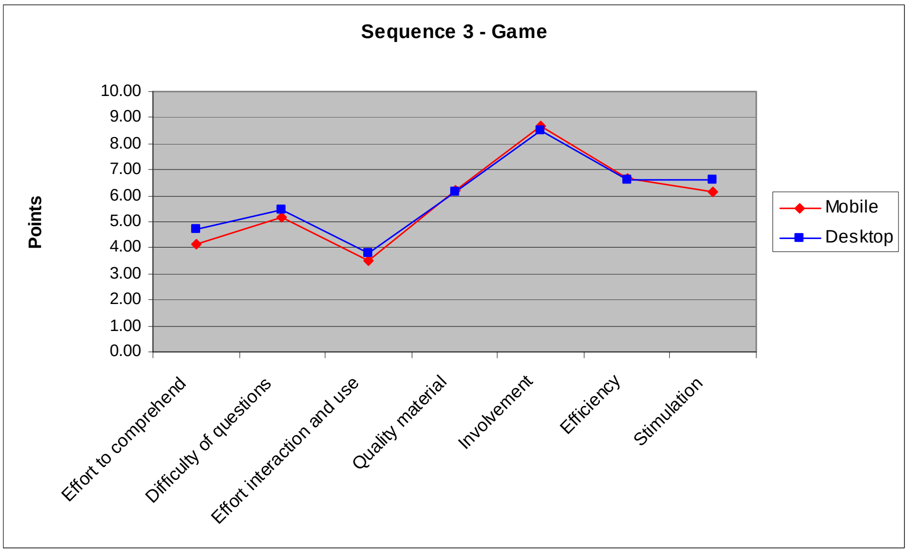


Figure 25: Mean perceived cognitive load and perception of learning material – Sequence 3

4.1.5 Animation

MG participants clearly needed more time to achieve their tasks, but they also attained better results in the knowledge test. Significant results could be reported in terms of time [$F(1,33)=7.060$, $MSE=36616.618$, $p<.05$] and score [$F(1,33)=9.405$, $MSE=64.971$, $p<.05$].

Whereas the small screen augmented the time spent on the learning material in average for 66 seconds for mobile phone users, the average score was 14 points for MG members comparing to 11.24 points for DG members.

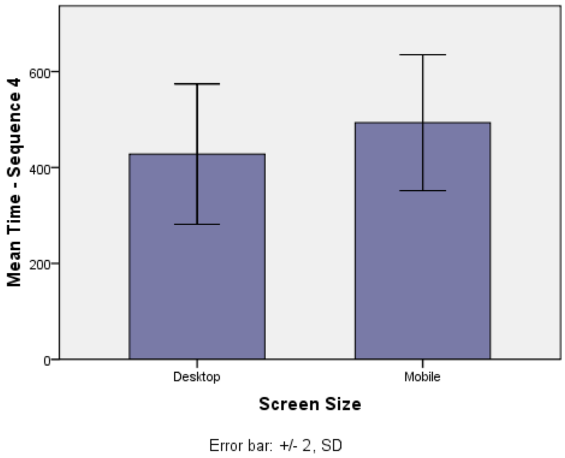


Figure 26: Mean Time - Sequence 4

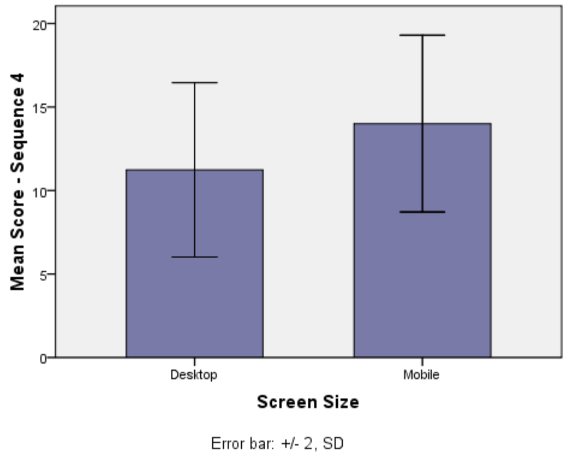


Figure 27: Mean Score - Sequence 4

Analyzing the two components of the variable *Time,* we see that participants spent more time studying the learning material and answering the questions. The results of both variables – *Instruction Time* [$F(1,33)=4.646$, $MSE=3205.057$, $p<.05$] and *Response Time* [$F(1,33)=6.178$, $MSE=18155.262$, $p<.05$] could be reported as significant.

The animation sequence was not only the longest duration, but also the most challenging in terms of the presented subject matter and the questions posed. MG participants rated the level of difficulty on the one-tenth scale at 7.47, DG participants even at 7.94.

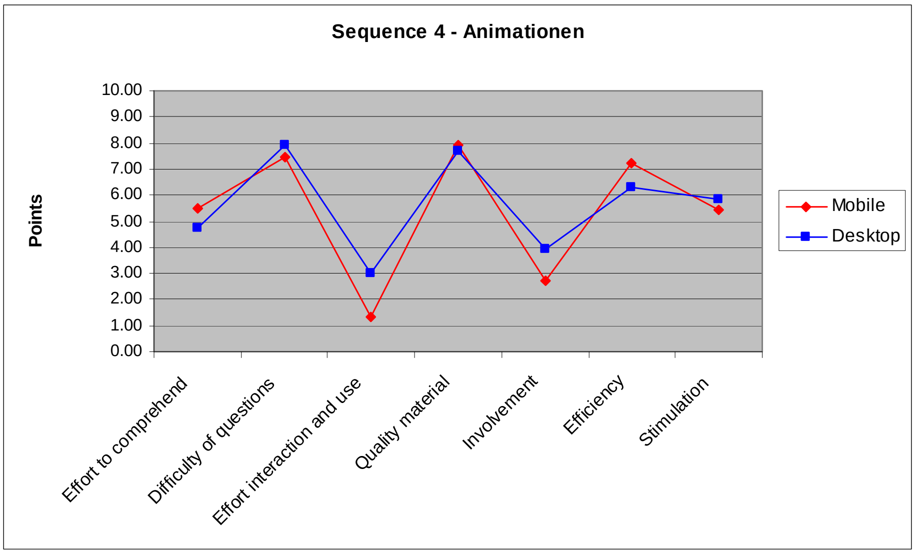


Figure 28: Mean perceived cognitive load and perception of learning material – Sequence 4

4.2 Discussion

Within the conditions of this study, the results indicate that reduced screen size do not automatically minimize students' learning performance nor affect the perceived cognitive load or the perception of the learning material – if the proposed multimedia material is represented at least 'somewhat media appropriate'. This means when the task is still manageable by the learners' mental resources and the application operational by the medium.

4.2.1 Time

The average time to achieve the entire learning module was for the *Mobile Group* more than 2 minutes higher than for the *Desktop Group*. This could be explained by reduced playback performance and screen size automatically imposing a slower learning pace.
Interestingly, while the overall time to follow the instructions was not significant between the two groups, the overall time to answer the question was. Mobile users took significantly more time to answer than desktop users – an indication that small-screen mobile devices do decelerate in particular the pace during reasoning.
Whether a slower learning pace does lead to better learning results, could not be answered conclusively by the study.

Considering each learning sequences separately, a significant difference in time was only found for the animation sequence – the longest and most challenging part of the module. Users needed more time for both, following the instructions and answering the questions. It seems that with a long and resource intensive task as well with increasing complexity the time factor starts to become important. We can argue that screen size has an influence on time when performing a complex and/or a long task. For simple tasks such as reading a short text passage or watching a video clip there were only marginal differences, even when the proposed material was not fully optimized for the target media.

However, the hypothesis that small screen-mobile devices increase the time to complete a task is valid for the animation sequence, but it must be rejected for the video, the text and the game sequence.

4.2.2 Score

The obviously better score results of participants in the *Mobile Group* reveals that smaller screen size conditions are not implicitly connected with a lessening of comprehension. At least in this study, small-screen mobile devices did not negatively affect cognitive processes such as recall and understanding tasks in short mobile multimedia learning units. To the contrary, the responses in the test proved that a small screen could even lead to better results even when the learning material is not perfectly optimized for mobile devices – a key finding of this study.

The fact that participants scored in total better in the knowledge test on a small screen is surprising at first glance. But it has to be admitted that the multimedia learning material was thought from the beginning to be used on a mobile phone with its reduced screen size and its limited technical capacities. This meant that the length and complexity of the exercises were limited; and the interaction and input

activities reduced to a minimum. The material was prepared in small learning units to be useable on a small-screen-low-performance device.
It seems that this combination was effective on a cognitive but also on a technical and formal level; and it worked better on a mobile device than on a desktop computer. Especially beneficial was this combination for the text and animation sequences where participants of the mobile group achieved significantly better results.

The hypothesis assuming that a small screen leads to an inferior score in the knowledge test must be rejected in all cases of the used multimedia material, rather it could be said, that a small screen could even lead to better results like in the animation and text sequence.

4.2.3 Perceived cognitive load

Participants in both groups perceived their cognitive load quite similarly for all learning sequences, despite different screen conditions.
This can be explained by the formal disposition of the learning material which was nearly identical for large and small screens. When comparing the results of the assessment made in chapter 1.2.4, we see that the measurements of the *Media Type Attributes* do not vary extremely between the two learning conditions.
It could be argued that if the learning material ranges within a particular 'tolerance zone', people react in a tolerant way and perceive no differences in terms of cognitive load. To find out the limits of such zones, further research would be necessary.
From a psychological point of view, there was no difference in how users processed information as they were presented in a similar way. And it seems also, that usability issues and the unfamiliar interaction conditions were, at least in our case, less of a disturbing factor in terms of the cognitive process than assumed.

However, the hypothesis that participants on a small-screen mobile device perceive a higher cognitive load must be rejected for all learning sequences.

4.2.4 Perception of the learning material

Reduced screen size was not necessarily associated with a loss of quality.
In their perception of the learning material, participants have not been influenced by objective criteria such as screen size and image resolution.
Although the quality of the video clip image was objectively worse on the mobile phone than on the desktop computer, mobile users judged it better than desktop users. Mobile users also rated the legibility of the text passage higher despite reduced information display, more line breaks and scrolling.
This is probably an indication that participants' judgment was not influenced by objective criteria, but by media-related expectations. To watch a video on a mobile phone seems to lower students expectations so that they are less likely to rate the quality as bad. On the other hand, higher video quality embedded in a familiar media context such as desktop computers leads to higher expectations.

The hypothesis that participants on a small screen perceive the learning material worse must be rejected in relation to this study situation.

4.3 Conclusion

4.3.1 Recommendations

The goal of this study to gather information about the appropriateness of different multimedia types on a small-screen mobile device has been fulfilled.
Based on the surprisingly positive results, it can be said that small-screen mobile devices do not a priori handicap students' learning performances in cognitive and perceptional terms. Different *Media Types* such as video, text, games or animations could be used for learning activities on small-screen mobile devices when some basic technical and formal requirements are preserved.

With a lot of information from the relevant literature and accumulated experience in my capacity as instructional designer and researcher in mind, I am going to summarize some important points necessary for a successful integration of mobile multimedia applications on small screen mobile devices. The following summary does not only include findings of the experiment, but also of the theory presented in the second chapter and the experiences I made during the development of the learning material.

- Data processing

A main condition for a successful integration of multimedia applications is their technical compatibility. Multimedia applications have to fulfill technical requirements and standards imposed by the target media platform such as file format, processing, storage and memory capacities, etc.
For an unproblematic playback the material has to be tested under different 'extreme' conditions, for instance, by nearly uncharged battery power, while running more than one application on the same time or while manipulating diverse combinations of the associated input buttons, 'zones' or keys.

- Complexity

The learning sequences developed for this study were relatively short taking into consideration the technical constraints of the device, and its limited capacities to perform multimedia content without interruption or delay. Portioning the content in short and independent learning units is beneficial in a mobile learning context and helps to avoid fatigue and frustration.

The use of complex learning material or demanding tasks for small screen mobile devices is not *a priori* excluded, but it has to be kept in mind that an increasing complexity requires also an increasing time investment, not only to develop and design these multimedia learning materials but also to perform complex tasks, to obtain, understand and process information.

- Interaction

Interaction should be adapted to the input capabilities of the device. In most cases these are still very limited or have to be tested and better examined under usability aspects, as in the case of the finger touch-screen devices which are available on the market and have appeared to be successful.

To involve users more actively, the material should be designed to permit easy control and navigation functions or offer simple interaction opportunities via two finger key press or interactive touch-screen zones.

- Aesthetics

Aesthetics should be a means to an end and not self-serving. A reduced, concise style helps in accentuating the important elements.
Fancy and unnecessary graphic elements should be avoided, font type and size should be adapted to be legible on a small screen, foreground and background colour combinations provide a sufficient contrast even in extreme light conditions.

- Workload

To overcome the limitations of screen size, verbal and visual information should be chosen very selectively and portioned in clearly arranged small units to avoid an overload of information and a loss of ease of use.
The addition of sound and voice could help to improve understanding especially when cognitively demanding visual information is transmitted at the same time.

4.3.2 Limitations

The theoretical framework of this study was very heterogeneous using different approaches from different disciplines – philosophy, education, psychology, media and communication theories. This mixture was interesting from an ontological point of view, but it has complicated the issue of linking theories and of keeping the main focus.
It also has to be noted that the lack of theories and previous findings in this particular field of research forced me to go my own way and to challenge and revise existing models. The *Media Appropriateness* theory developed in this study should be seen as an attempt to approach the question about the appropriate use of multimedia on small screen-mobile devices under formal aspects; it is a first draft, which can help evaluate and optimize multimedia learning material, but it is still immature and insufficient as theoretical foundations.

The findings of this study revealed, that individuals do not judge and operate according rational criteria or a predefined schema.
The developed *Media Appropriateness* theory represents a rational perspective assuming that an appropriate choice for multimedia learning material could be objectively determined by an accord between the inherent characteristics of the chosen medium and formal requirements. Despite the inclusion of a human factor – the attribute workload – this perspective seems too limited.
In contrast, cognitive theories of multimedia learning remain also incomplete as they neglect in their perspective important parameters for an eclectic understanding of the human learning process – for example – the influence of the 'level of technology' (Schnotz, 2005).

There are probably more commonalities than differences between mobile phones and desktop computers, but as Fisch (2004) noticed each new medium presents its own particular issues, challenges and constraints.

If we consider the different score results between the two groups, performed on two different media, with an identical test material – which has been perceived and judged nearly similar – we may argue that the medium itself had an effect on learning and that comprehension is not only dependent on the method and information presented, but also on the medium on which it is presented. The influential factors inherent in that use are difficult to depict conclusively, but certainly they are not limited to intrinsic characteristics and attributes of a medium.

Screen size was, in the case of this study, a 'cognitively relevant characteristic' (Kozma, 1991) but only one of a complex ensemble of individual, context and media related factors which have influenced not only users' perception but also their appreciation and motivation towards learning.

From this perspective, the theoretical framework and the experimental design of this study should be reconsidered; and the results seen in a broader context of mobile learning studies which are approaching the multidimensional reality of human-computer interaction (Kaptelinin, 1996) with different methods and with complementary theories and points of views.

4.3.3 Future Work

To better understand the strengths and weaknesses of small-screen mobile devices and their potential for a successful integration of multimedia content for learning, there are still a number of unknown avenues to explore.
Investigations could be extended in different directions: in a more design-based approach including aspects of usability and ergonomics, towards a deeper insight into cognitive science and psychology or into communication and media theories.

All multimedia learning sequences developed for this study delivered quite good or satisfactory results. To be able to formulate more precisely requirements for the use of multimedia on mobile devices, it would be necessary to explore the limits of their appropriateness in a mobile setting. To have more information, media types should be examined separately, thus permitting variations of specific characteristics as complexity, interaction, aesthetics etc. to understand better the relation between medium, formal requirements and learning.

According to Schnotz (2005) cited earlier in this study, comprehension is highly dependent on how information is presented. Small-screen mobile devices have their proper modality with which to convey information. A typical characteristic could be found in its chunk size architecture. Information is chosen more selectively and split up in small units as was the case of the learning material used for this study. To better understand how this type of information architecture affects cognitive processes in multimedia learning, further investigation is needed.
Studies in the same direction could investigate more closely the importance of the time factor, and how cognitive processes are affected by decelerating while performing complex learning tasks on a small-screen mobile device.

The study took place in a media room, an atypical place for a mobile context. Further research should be undertaken to explore how contexts such as waiting halls, train or bus stations or transportation situations affect learning with different media types.

Furthermore there is a need to gather information on how other relevant factors besides screen size, such as the novelty aspect of mobile devices, influence user's motivation, expectations and attitude towards learning with multimedia material on mobile devices.

This study was an attempt to explore the potential for a multimedia integration on small-screen mobile devices. Hence, the first step into mobile learning has been done. The results of the experiment were very promising and the experiences and insights accumulated during this study provide an important background and the confidence required to concretize projects in real settings and learning situations.

The tough nut to crack will be convincing teachers about the usefulness of mobile technology, and to develop scenarios which are efficient, practicable and beneficial for those actively involved in learning and teaching.

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6 Annexes

Total Time Sequence 1,2,3,4
Overall Time Sequences 1 - 4

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum	Between- Component Variance
							Lower Bound	Upper Bound			
Total Time Sequence 1	Desktop		17	385.57	45.523	11.041	362.16	408.97	315	454	
	Mobile		17	414.97	52.722	12.787	387.86	442.07	337	510	
	Total		34	400.27	50.745	8.703	382.56	417.97	315	510	
	Model	Fixed Effects			49.254	8.447	383.06	417.47			
		Random Effects				14.700	213.48	587.05			289.494
Total Time Sequence 2	Desktop		17	378.94	79.637	19.315	338.00	419.89	260	550	
	Mobile		17	378.01	58.973	14.303	347.69	408.34	309	517	
	Total		34	378.48	69.003	11.834	354.40	402.56	260	550	
	Model	Fixed Effects			70.071	12.017	354.00	402.96			
		Random Effects				12.017[a]	225.79[a]	531.17[a]			-288.386
Total Time Sequence 3	Desktop		17	422.89	69.969	16.970	386.92	458.87	309	552	
	Mobile		17	466.89	97.092	23.548	416.97	516.81	337	791	
	Total		34	444.89	86.271	14.795	414.79	474.99	309	791	
	Model	Fixed Effects			84.624	14.513	415.33	474.45			
		Random Effects				21.997	165.39	724.39			546.500

Total Time Sequence 4	Desktop		17	427.87	73.204	17.755	390.24	465.51	307	570	
	Mobile		17	493.51	70.811	17.174	457.10	529.92	394	638	
	Total		34	460.69	78.351	13.437	433.35	488.03	307	638	
	Model	Fixed Effects			72.018	12.351	435.53	485.85			
		Random Effects				32.817	43.71	877.67			1848.829
Total Time Sequences 1 - 4	Desktop		17	1615.28	228.743	55.478	1497.67	1732.88	1294	2002	
	Mobile		17	1753.43	177.695	43.097	1662.07	1844.80	1400	2139	
	Total		34	1684.35	213.529	36.620	1609.85	1758.86	1294	2139	
	Model	Fixed Effects			204.816	35.126	1612.81	1755.90			
		Random Effects				69.079	806.62	2562.09			7076.211

a. Warning: Between-component variance is negative. It was replaced by 0.0 in computing this random effects measure.

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Total Time Sequence 1	.713	1	32	.405
Total Time Sequence 2	1.187	1	32	.284
Total Time Sequence 3	.030	1	32	.863
Total Time Sequence 4	.065	1	32	.801
Total Time Sequences 1 -4	2.687	1	32	.111

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Total Time Sequence 1	Between Groups	7347.354	1	7347.354	3.029	.091
	Within Groups	77630.448	32	2425.952		
	Total	84977.802	33			

Total Time Sequence 2	Between Groups	7.348	1	7.348	.001	.969
	Within Groups	157117.361	32	4909.918		
	Total	157124.709	33			
Total Time Sequence 3	Between Groups	16451.732	1	16451.732	2.297	.139
	Within Groups	229159.258	32	7161.227		
	Total	245610.990	33			
Total Time Sequence 4	Between Groups	36616.618	1	36616.618	7.060	.012
	Within Groups	165968.693	32	5186.522		
	Total	202585.311	33			
Total Time Sequences 1 - 4	Between Groups	162245.018	1	162245.018	3.868	.058
	Within Groups	1342381.580	32	41949.424		
	Total	1504626.599	33			

Total Score Sequence 1,2,3,4
Overall Score Sequences 1 - 4

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum	Between- Component Variance
Total Score Sequence 1	Desktop		17	8.0588	2.16421	.52490	6.9461	9.1716	4.00	11.00	
	Mobile		17	8.5294	1.66274	.40327	7.6745	9.3843	5.00	10.00	
	Total		34	8.2941	1.91532	.32847	7.6258	8.9624	4.00	11.00	
	Model	Fixed Effects			1.92984	.33096	7.6200	8.9683			
		Random Effects				.33096[a]	4.0888[a]	12.4994[a]			-.10835
Total Score Sequence 2	Desktop		17	6.53	1.375	.333	5.82	7.24	4	9	
	Mobile		17	7.35	.996	.242	6.84	7.87	5	9	
	Total		34	6.94	1.254	.215	6.50	7.38	4	9	
	Model	Fixed Effects			1.200	.206	6.52	7.36			
		Random Effects				.412	1.71	12.17			.254
Total Score Sequence 3	Desktop		17	24.00	6.819	1.654	20.49	27.51	11	36	

	Mobile	17	29.00	8.839	2.144	24.46	33.54	8	40	
	Total	34	26.50	8.177	1.402	23.65	29.35	8	40	
	Mo-del Fixed Effects			7.894	1.354	23.74	29.26			
	Random Effects				2.500	-5.27	58.27			8.835
Total Score Sequence 4	Desktop	17	11.24	2.611	.633	9.89	12.58	6	16	
	Mobile	17	14.00	2.646	.642	12.64	15.36	8	18	
	Total	34	12.62	2.944	.505	11.59	13.64	6	18	
	Mo-del Fixed Effects			2.628	.451	11.70	13.54			
	Random Effects				1.382	-4.95	30.18			3.415
Total Score Sequences 1 - 4	Desktop	17	49.82	6.579	1.596	46.44	53.21	35	60	
	Mobile	17	58.88	10.404	2.523	53.53	64.23	31	71	
	Total	34	54.35	9.726	1.668	50.96	57.75	31	71	
	Mo-del Fixed Effects			8.704	1.493	51.31	57.39			
	Random Effects				4.529	-3.20	111.90			36.575

a. Warning: Between-component variance is negative. It was replaced by 0.0 in computing this random effects measure.

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Total Score Sequence 1	.764	1	32	.389
Total Score Sequence 2	1.358	1	32	.253
Total Score Sequence 3	.497	1	32	.486
Total Score Sequence 4	.062	1	32	.805

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Total Score Sequence 1	.764	1	32	.389
Total Score Sequence 2	1.358	1	32	.253
Total Score Sequence 3	.497	1	32	.486
Total Score Sequence 4	.062	1	32	.805
Total Score Sequences 1 - 4	2.976	1	32	.094

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Total Score Sequence 1	Between Groups	1.882	1	1.882	.505	.482
	Within Groups	119.176	32	3.724		
	Total	121.059	33			
Total Score Sequence 2	Between Groups	5.765	1	5.765	4.000	.054
	Within Groups	46.118	32	1.441		
	Total	51.882	33			
Total Score Sequence 3	Between Groups	212.500	1	212.500	3.410	.074
	Within Groups	1994.000	32	62.312		
	Total	2206.500	33			
Total Score Sequence 4	Between Groups	64.971	1	64.971	9.405	.004
	Within Groups	221.059	32	6.908		
	Total	286.029	33			
Total Score Sequences 1 - 4	Between Groups	697.529	1	697.529	9.207	.005
	Within Groups	2424.235	32	75.757		
	Total	3121.765	33			

Total Instruction Time Sequence 1,2,3,4
Overall Instruction Time Sequences 1 - 4

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum	Between-Component Variance
							Lower Bound	Upper Bound			
Instruction Time Sequence 1	Desktop		17	221.46	29.804	7.229	206.13	236.78	179	270	
	Mobile		17	229.24	22.452	5.445	217.69	240.78	192	280	
	Total		34	225.35	26.281	4.507	216.18	234.52	179	280	
	Model	Fixed Effects			26.385	4.525	216.13	234.56			
		Random Effects				4.525[a]	167.85[a]	282.84[a]			-10.689
Instruction Time Sequence 2	Desktop		17	258.91	72.623	17.614	221.57	296.25	162	445	
	Mobile		17	260.74	53.864	13.064	233.05	288.44	206	396	
	Total		34	259.82	62.966	10.799	237.85	281.79	162	445	
	Model	Fixed Effects			63.935	10.965	237.49	282.16			
		Random Effects				10.965[a]	120.50[a]	399.14[a]			-238.765
Instruction Time Sequence 3	Desktop		17	53.64	12.278	2.978	47.32	59.95	39	79	
	Mobile		17	52.40	6.802	1.650	48.90	55.89	39	63	
	Total		34	53.02	9.794	1.680	49.60	56.43	39	79	
	Model	Fixed Effects			9.925	1.702	49.55	56.48			
		Random Effects				1.702[a]	31.39[a]	74.64[a]			-5.025
Instruction Time Sequence 4	Desktop		17	242.57	28.133	6.823	228.11	257.04	199	298	
	Mobile		17	261.99	24.254	5.882	249.52	274.46	230	318	
	Total		34	252.28	27.678	4.747	242.62	261.94	199	318	
	Model	Fixed Effects			26.265	4.504	243.11	261.46			

		Random Effects				9.709	128.91	375.65			147.953
Instruction Time Sequences 1-4	Desktop		17	1405.60	198.565	48.159	1303.51	1507.69	1129	1752	
	Mobile		17	1516.18	151.705	36.794	1438.18	1594.18	1227	1859	
	Total		34	1460.89	182.825	31.354	1397.10	1524.68	1129	1859	
	Model	Fixed Effects			176.695	30.303	1399.17	1522.62			
		Random Effects				55.291	758.35	2163.43			4277.611

a. Warning: Between-component variance is negative. It was replaced by 0.0 in computing this random effects measure.

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Instruction Time Sequence 1	4.083	1	32	.052
Instruction Time Sequence 2	.928	1	32	.343
Instruction Time Sequence 3	4.055	1	32	.053
Instruction Time Sequence 4	.324	1	32	.573
Instruction Time Sequences 1 - 4	2.680	1	32	.111

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Instruction Time Sequence 1	Between Groups	514.464	1	514.464	.739	.396
	Within Groups	22277.543	32	696.173		
	Total	22792.007	33			
Instruction Time Sequence 2	Between Groups	28.678	1	28.678	.007	.934
	Within Groups	130805.939	32	4087.686		
	Total	130834.618	33			
Instruction Time Sequence 3	Between Groups	13.089	1	13.089	.133	.718
	Within Groups	3152.235	32	98.507		
	Total	3165.324	33			
Instruction Time	Between Groups	3205.057	1	3205.057	4.646	.039

	Within Groups	22075.668	32	689.865		
	Total	25280.725	33			
Instruction Time Sequences 1 - 4	Between Groups	103940.680	1	103940.680	3.329	.077
	Within Groups	999081.199	32	31221.287		
	Total	1103021.879	33			

Total Response Time Sequence 1,2,3,4
Overall Response Time Sequences 1 - 4

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum	Between-Component Variance
							Lower Bound	Upper Bound			
Response Time Sequence 1	Desktop		17	164.11	34.409	8.345	146.42	181.80	99	251	
	Mobile		17	185.73	38.813	9.414	165.77	205.69	141	262	
	Total		34	174.92	37.747	6.474	161.75	188.09	99	262	
	Model	Fixed Effects			36.677	6.290	162.11	187.73			
		Random Effects				10.810	37.56	312.28			154.600
Response Time Sequence 2	Desktop		17	120.04	27.252	6.610	106.03	134.05	73	173	
	Mobile		17	117.27	27.754	6.731	103.00	131.54	78	176	
	Total		34	118.65	27.120	4.651	109.19	128.12	73	176	
	Model	Fixed Effects			27.504	4.717	109.05	128.26			
		Random Effects				4.717[a]	58.72[a]	178.59[a]			-40.671
Response Time Sequence 3	Desktop		17	369.25	68.439	16.599	334.07	404.44	262	501	
	Mobile		17	414.49	95.458	23.152	365.41	463.57	294	738	

	Total		34	391.87	84.947	14.568	362.23	421.51	262	738	
	Model	Fixed Effects			83.054	14.244	362.86	420.89			
		Random Effects				22.618	104.49	679.26			617.347
Response Time Sequence 4	Desktop		17	185.30	49.920	12.107	159.64	210.97	109	285	
	Mobile		17	231.52	58.180	14.111	201.61	261.43	164	377	
	Total		34	208.41	58.306	9.999	188.07	228.76	109	377	
	Model	Fixed Effects			54.208	9.297	189.47	227.35			
		Random Effects				23.108	-85.20	502.03			895.105
Response Time Sequences 1 - 4	Desktop		17	209.68	32.229	7.817	193.11	226.25	162	258	
	Mobile		17	237.25	31.375	7.610	221.12	253.38	173	306	
	Total		34	223.46	34.304	5.883	211.49	235.43	162	306	
	Model	Fixed Effects			31.805	5.454	212.35	234.57			
		Random Effects				13.788	48.27	398.66			320.724

a. Warning: Between-component variance is negative. It was replaced by 0.0 in computing this random effects measure.

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Response Time Sequence 1	.988	1	32	.328
Response Time Sequence 2	.008	1	32	.929
Response Time Sequence 3	.011	1	32	.917
Response Time Sequence 4	.207	1	32	.653
ResponseTime Sequences 1 - 4	.892	1	32	.352

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Response Time Sequence 1	Between Groups	3973.399	1	3973.399	2.954	.095
	Within Groups	43046.157	32	1345.192		
	Total	47019.556	33			
Response Time Sequence 2	Between Groups	65.059	1	65.059	.086	.771
	Within Groups	24206.881	32	756.465		
	Total	24271.940	33			
Response Time Sequence 3	Between Groups	17392.925	1	17392.925	2.521	.122
	Within Groups	220737.086	32	6898.034		
	Total	238130.011	33			
Response Time Sequence 4	Between Groups	18155.262	1	18155.262	6.178	.018
	Within Groups	94031.006	32	2938.469		
	Total	112186.269	33			
Response Time Sequences 1 - 4	Between Groups	6463.866	1	6463.866	6.390	.017
	Within Groups	32369.667	32	1011.552		
	Total	38833.533	33			

Perceived Cognitive Load and Perception of Learning Material - Sequence 1: Video

Bericht

Screen Size Medium			Sub_S1A1	Sub_S1A2	Sub_S1A3	Sub_S1A4	Sub_S1A5	Sub_S1A6	Sub_S1A7
Desktop	Insgesamt	Mittelwert	4.12	5.41	5.88	2.24	4.29	7.18	6.47
		N	17	17	17	17	17	17	17
		Standardabweichung	2.088	2.063	1.833	2.047	2.229	1.286	1.586
Mobile	Insgesamt	Mittelwert	3.94	6.24	5.88	2.06	3.41	7.53	6.82
		N	17	17	17	17	17	17	17
		Standardabweichung	2.076	1.715	1.933	1.088	1.938	1.908	1.237
Insgesamt	Insgesamt	Mittelwert	4.03	5.82	5.88	2.15	3.85	7.35	6.65
		N	34	34	34	34	34	34	34
		Standardabweichung	2.052	1.914	1.855	1.617	2.105	1.612	1.412

		Mobile Mean (1-10)	Desktop Mean (1-10)
S1A1	**How difficult was it to follow the video?** *Wie schwierig fanden Sie es, dem Video zu folgen?*	3.94	4.12
S1A2	**How good was the quality of the video image?** *Wie gut fanden Sie die Bildqualität des Videos?*	6.24	5.41
S1A3	**How difficult did you find the questions?** *Wie anspruchsvoll fanden Sie die gestellten Fragen?*	5.88	5.88
S1A4	**How difficult was it to navigate on the display and to understand what kind of action had to be executed?** *Wie schwierig war es, sich auf dem Display zurechtzufinden und zu verstehen, welche Aktion ausgeführt werden muss?*	2.06	2.24
S1A5	**Were you more passively or actively involved while doing the exercises?** *Fühlten Sie sich mehr passiv oder aktiv beim Ausführen der Aufgabe?*	3.41	4.29
S1A6	**Was the video helpful for you in mediating the content of the exercise?** *Haben Sie den Eindruck, dass das Video effizient war, um Ihnen den Inhalt zu vermitteln?*	7.53	7.18
S1A7	**Did you find the learning activity interesting?** *Hat Sie das Thema angesprochen und Ihnen die Aufgabe Spass gemacht?*	6.82	6.47

Perceived Cognitive Load and Perception of Learning Material - Sequence 2: Text

Bericht

Screen Size Medium			Sub_S2A1	Sub_S2A2	Sub_S2A3	Sub_S2A4	Sub_S2A5	Sub_S2A6	Sub_S2A7
Mobile	Insgesamt	Mittelwert	6.00	4.53	6.71	3.06	4.41	5.06	4.00
		N	17	17	17	17	17	17	17
		Standardabweichung	2.121	2.401	1.611	2.164	2.623	2.164	2.000
Desktop	Insgesamt	Mittelwert	5.59	6.94	6.47	2.76	4.76	5.53	4.18
		N	17	17	17	17	17	17	17

		Standardabweichung	2.451	1.853	1.841	2.463	2.306	1.841	2.069
Insgesamt	Insgesamt	Mittelwert	5.79	5.74	6.59	2.91	4.59	5.29	4.09
		N	34	34	34	34	34	34	34
		Standardabweichung	2.267	2.441	1.708	2.288	2.439	1.993	2.006

		Mobile Mean (1-10)	**Desktop** Mean (1-10)
S2A1	**How difficult was it to understand the text?** *Wie schwierig fanden Sie es, den Text zu verstehen?*	5.59	6.00
S2A2	**How good was the legibility in term of text size, wrap and paragraphs?** *Wie gut empfanden Sie die Leserlichkeit des Textes - Textgrösse, Umbruch, Abschnitte?*	6.94	4.53
S2A3	**How difficult did you find the questions?** *Wie anspruchsvoll fanden Sie die gestellten Fragen?*	6.47	6.71
S2A4	**How difficult was it to navigate on the display and to understand what kind of action had to be executed?** *Wie schwierig war es, sich auf dem Display zurechtzufinden und zu verstehen, welche Aktion ausgeführt werden muss?*	2.76	3.06
S2A5	**Were you more passively or actively involved while doing the exercises?** *Fühlten Sie sich mehr passiv oder aktiv beim Ausführen der Aufgabe?*	4.76	4.41
S2A6	**Were the text and the table helpful for you in mediating the content of the exercise?** *Haben Sie den Eindruck, dass der Text und die Tabelle effizient waren, um Ihnen den Inhalt zu vermitteln?*	5.53	5.06
S2A7	**Did you find the learning activity interesting?** *Hat Sie das Thema angesprochen und Ihnen die Aufgabe gemacht?*	4.18	4.00

Perceived Cognitive Load and Perception of Learning Material - Sequence 3: Game

Bericht

Screen Size Medium			Sub_S3A1	Sub_S3A2	Sub_S3A3	Sub_S3A4	Sub_S3A5	Sub_S3A6	Sub_S3A7
Mobile	Insgesamt	Mittelwert	4.71	6.18	5.47	3.76	8.53	6.59	6.59
		N	17	17	17	17	17	17	17
		Standardabweichung	2.312	2.215	2.004	2.635	1.940	2.551	2.599
Desktop	Insgesamt	Mittelwert	4.12	6.24	5.18	3.53	8.71	6.65	6.18
		N	17	17	17	17	17	17	17
		Standardabweichung	2.667	2.611	1.811	2.322	2.024	2.572	2.298
Insgesamt	Insgesamt	Mittelwert	4.41	6.21	5.32	3.65	8.62	6.62	6.38
		N	34	34	34	34	34	34	34
		Standardabweichung	2.476	2.384	1.886	2.448	1.954	2.523	2.425

		Mobile Mittelwert (1-10)	Desktop Mittelwert (1-10)
S3A1	**How difficult was it to follow the presentation of the points of sail?** *Wie verständlich fanden Sie die Präsentationen der Segel-Kurse?*	4.12	4.71
S3A2	**How good was the quality of the game?** *Wie gut fanden Sie die Umsetzung des Games?*	6.24	6.18
S3A3	**How difficult was it to play the game?** *Wie anspruchsvoll fanden Sie das Game?*	5.18	5.47
S3A4	**How difficult was it to navigate on the display and to understand what kind of action had to be executed?** *Wie schwierig war es beim Game, sich auf dem Display zurechtzufinden und zu verstehen, welche Aktion ausgeführt werden muss?*	3.53	3.76
S3A5	**Were you more passively or actively involved while doing the exercises?** *Fühlten Sie sich mehr passiv oder aktiv beim Ausführen der Aufgabe?*	8.71	8.53
S3A6	**Was the game helpful for you in mediating the content of the exercise?** *Haben Sie den Eindruck, dass das Game effizient war, um die Segel-*	6.65	6.59

	Kurse zu lernen?		
S3A7	**Did you find the learning activity interesting?** *Hat Sie das Thema angesprochen und Ihnen die Aufgabe mit dem Game Spass gemacht?*	6.18	6.59

Perceived Cognitive Load and Perception of Learning Material - Sequence 4: Animations

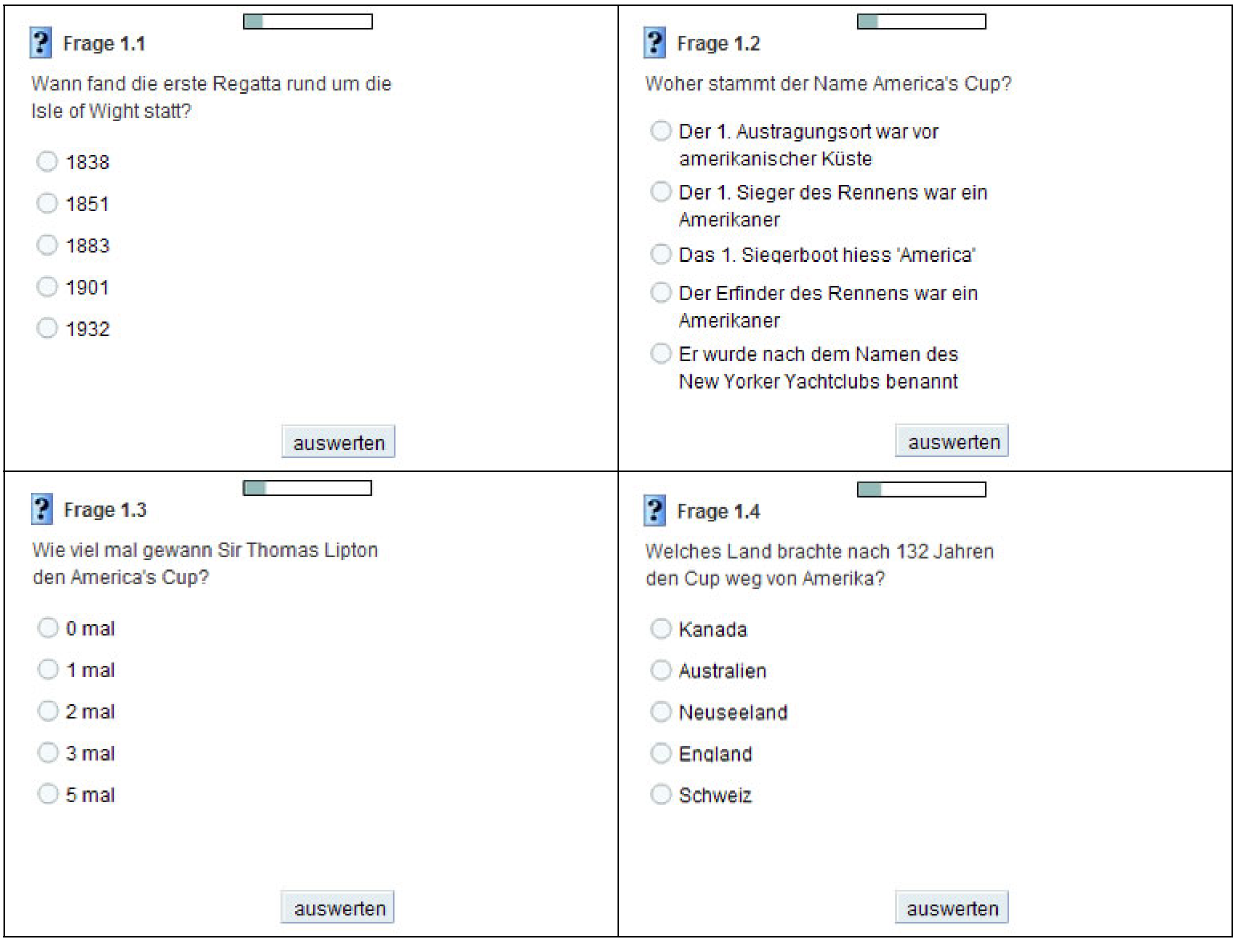
Bericht

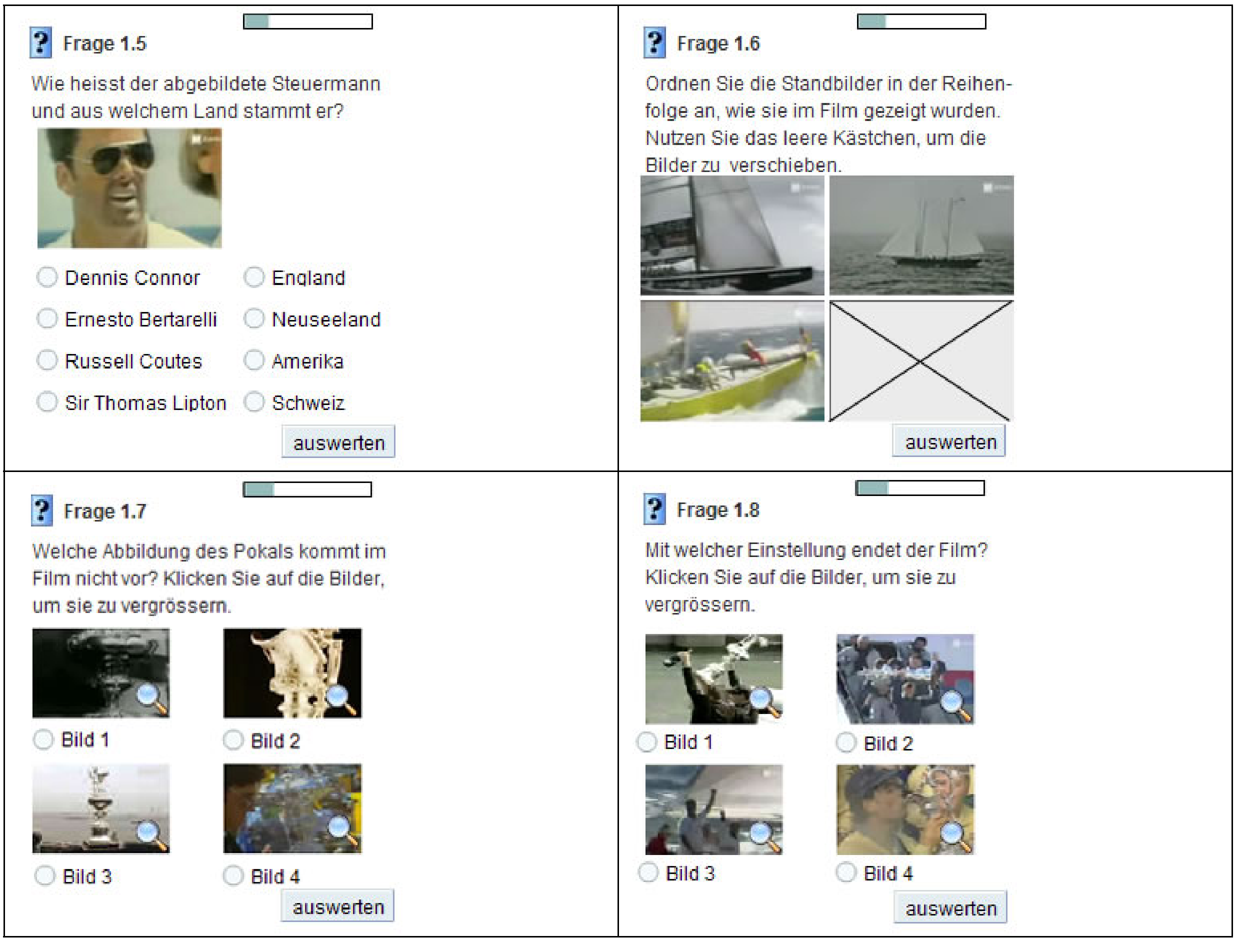
Screen Size Medium			Sub_S4A1	Sub_S4A2	Sub_S4A3	Sub_S4A4	Sub_S4A5	Sub_S4A6	Sub_S4A7
Mobile	Insgesamt	Mittelwert	4.76	7.71	7.94	3.00	3.94	6.29	5.82
		N	17	17	17	17	17	17	17
		Standardabweichung	1.954	1.404	1.391	2.092	1.886	1.961	2.506
Desktop	Insgesamt	Mittelwert	5.47	7.94	7.47	1.35	2.71	7.24	5.41
		N	17	17	17	17	17	17	17
		Standardabweichung	2.401	1.638	2.065	.606	1.312	1.821	2.551
Insgesamt	Insgesamt	Mittelwert	5.12	7.82	7.71	2.18	3.32	6.76	5.62
		N	34	34	34	34	34	34	34
		Standardabweichung	2.185	1.507	1.750	1.732	1.718	1.924	2.499

		Mobile Mittelwert (1-10)	Desktop Mittelwert (1-10)
S4A1	**How difficult was it to follow the animations?** *Wie verständlich fanden Sie die Animationen?*	5.47	4.76
S4A2	**How good did you find the design of the animations?** *Wie gut fanden Sie die Umsetzung der Animationen?*	7.94	7.71
S4A3	**How difficult did you find the questions?** *Wie anspruchsvoll fanden Sie die gestellten Aufgaben?*	7.47	7.94
S4A4	**How difficult was it to navigate on the display and to understand what kind of action had to be executed?** *Wie schwierig war es, sich auf dem Display zurechtzufinden und zu verstehen, welche Aktion ausgeführt werden muss?*	1.35	3.00

S4A5	**Were you more passively or actively involved while doing the exer-cises?** *Fühlten Sie sich mehr passiv oder aktiv beim Ausführen der Aufgabe?*	2.71	3.94
S4A6	**Were the animations helpful for you in mediating the content of the exercise?** *Haben Sie den Eindruck, dass die Animationen effizient waren, um Ihnen den Antrieb beim Segeln zu erklären?*	7.24	6.29
S4A7	**Did you find the learning activity interesting?** *Hat Sie das Thema angesprochen und Ihnen die Aufgabe Spass gemacht?*	5.41	5.82

Questions Sequence 1: Video





Questions Sequence 2: Text

Frage 2.3

Von wie viel Personen Besatzung wird das H-Boot bei einer Regatta gesegelt?

- 2 Personen
- 3 Personen
- 4 Personen
- 6 Personen
- 8 Personen

auswerten

Frage 2.4

Welche Aussagen sind richtig bzw. falsch?

Das H-Boot ist so beliebt wegen ...

... der gelungenen Synthese von Kajüten- und Regattaboot.

Richtig Falsch

der Sicherheit sowohl in rauhem Gewässer als auch bei starkem Wind

Richtig Falsch

... dem umfangreichen Zubehörangebot

Richtig Falsch

auswerten

Frage 2.5

Welche Aussagen sind richtig bzw. falsch?

Der Boden eines selbstlenzenden Cockpits liegt über der Wasseroberfläche.

Richtig Falsch

Konstrukteur des H-Bootes war ein Däne.

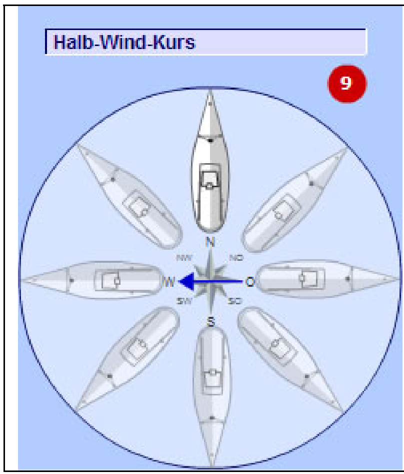
Richtig Falsch

Das H-Boot stellt europaweit die grösste Kielbootklasse dar.

Richtig Falsch

auswerten

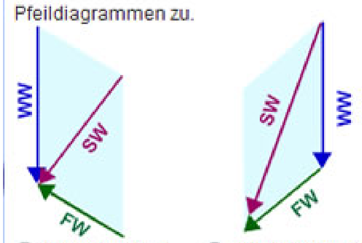
Points Sequence 3: Game



Questions Sequence 4: Animation

Aufgabe 4.1

Ordnen Sie den richtigen Kurs den Pfeildiagrammen zu.

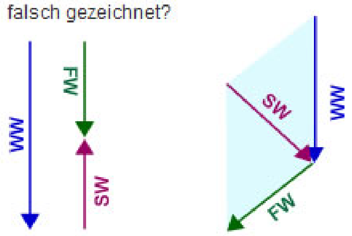


Am-Wind-Kurs	Am-Wind-Kurs
Halb-Wind-Kurs	Halb-Wind-Kurs
Raum-Wind-Kurs	Raum-Wind-Kurs

auswerten

Aufgabe 4.2

Sind die Pfeildiagramme richtig oder falsch gezeichnet?



richtig	richtig
falsch	falsch

auswerten

Aufgabe 4.3

Bei welchen Kursen ist normalerweise der scheinbare Wind grösser, bzw. kleiner als der wahre Wind?

Am-Wind	grösser	kleiner
Halb-Wind	grösser	kleiner
Raum-Wind	grösser	kleiner
Vor-dem-Wind	grösser	kleiner

auswerten

Aufgabe 4.4

Wie hoch ist die Geschwindigkeit des *scheinbaren Windes* bei einem **Vor-dem-Wind-Kurs**, wenn der Reibungsverlust nicht mitgerechnet wird?
Wahrer Wind (WW): **12 kn**
Fahrtwind (FW): **5 kn**

- WW - FW = 7 kn
- $\sqrt{WW^2 - FW^2} = 13$ kn
- WW + FW = 17 kn

auswerten

Aufgabe 4.5

Bei welchen Kursen wird ein Boot mittels Widerstand bzw. Auftrieb angetrieben? Klicken Sie die richtige(n) Antwort(en) an.

Vor-dem-Wind-Kurs
Widerstand Auftrieb

Am-Wind-Kurs
Widerstand Auftrieb

Halb-Wind-Kurs
Widerstand Auftrieb

Raum-Wind-Kurs
Widerstand Auftrieb

auswerten

Aufgabe 4.6

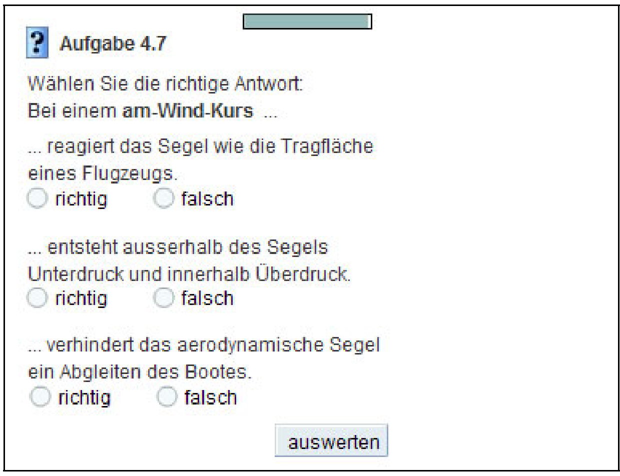
Wählen Sie die richtige Antwort:
Bei einem **Vor-dem-Wind-Kurs** ...

... wird am besten mit einem Spinnaker gesegelt.
richtig falsch

... bringt ein möglichst bauchiges Segel viel Auftrieb.
richtig falsch

... kann ein Boot bei wenig Wind sehr langsam werden.
richtig falsch

auswerten



Aufgabe 4.7

Wählen Sie die richtige Antwort:
Bei einem **am-Wind-Kurs** ...

... reagiert das Segel wie die Tragfläche eines Flugzeugs.
richtig falsch

... entsteht ausserhalb des Segels Unterdruck und innerhalb Überdruck.
richtig falsch

... verhindert das aerodynamische Segel ein Abgleiten des Bootes.
richtig falsch

auswerten