Learning with Hyperaudio: Cognitive Load and Knowledge Acquisition in Non-Linear Auditory Instruction

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Abstract

Learning with non-linear information media has become an established research area in applied learning sciences and cognitive psychology. Despite the huge amount of studies related to hypertext and hypermedia, there is little or no contemporary research on hyperaudio. In this paper we present the concept of hyperaudio and underlying theoretical assumptions of how hyperaudio differs from existing non-linear information media and can contribute to learning. We present a study comparing a linear hyperaudio learning environment with a non-linear hyperaudio learning environment in the domain of molecular biology. Results showed no significant outcomes related to measures of Cognitive Load as experienced by the participants. Contrary to our hypotheses, learners in the hyperaudio condition had higher learning outcomes than those in the linear audio condition. Results suggest that learning with hyperaudio opens a new research field offering a wide range of potential applications.

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Introduction

In applied learning sciences and cognitive psychology, scholarly papers related to issues of hypertext and hypermedia are prospering. Conversely, there is only little research in learning with hypervideo (e.g., Zahn, Schwan & Barquero, 2002) and no contemporary research on hyperaudio. We define hyperaudio as an arrangement of information that is presented exclusively on the auditory channel. Information is – correspondingly to hypertext – located within nodes (i.e., single audio files) that are locally coherent. These audionodes are connected via hyperlinks that enable users to navigate within a hyperaudio environment. By navigating these hyperaudio environment users should be able to understand the relationships between single audionodes and, thus, build global coherence. The possibilities of linking nodes and creating an overall navigation structure of a hyperaudio environment are the same as in common hypertexts or hypermedia environments. Nodes can be linked in a linear, in a hierarchical, in an elaborative, in an associate manner, etc. (cf. Grabinger & Dunlap, 1996).

A specific type of linear hyperaudio is currently widely used: the audiobook. Audiobooks are typically read versions of printed books (sometimes sound enriched) that do not have to meet the requirements of local coherence within single audionodes. There are fiction and non-fiction products available with a steadily growing offer and market. Yet, the structure of audiobooks is similar (linear) to that of printed books.

In contrast to audiobooks, we understand hyperaudio as a learning environment that enabled learners to navigate freely within a network of locally coherent audio. Especially current standards and developments in Software (data reduction, e.g., MP3) and portable hardware (e.g., portable MP3-Players, or integrated audioplayers in cellular phones) open a wide range of applications and can contribute to research on ubiquitous computing and learning with handheld computer devices (e.g., Hsi, 2003; Roschelle & Pea, 2002).

Development of a Hyperaudio Learning Environment.

In information society, nearly everyone is faced with non-linear audio especially in telecommunication. Automated helpdesk systems or voice mail boxes are predominantly hierarchically structured hyperaudio systems. A typical example is calling your voice mail box: “If you want to receive your new messages press 1"; "If you want to receive your old messages press 2"; "If you want to change your basics press 3", etc.

All of these systems are non-portable and only address issues of handling navigating non-instructional service offers. In our approach, we developed several prototypes of hyperaudio learning environments using a cellular phone metaphor. Due to experimental and technical constraints we simulated cellular phones run as computer programs (see Figure 1). The computer programs simulated a hyperaudio learning environment navigable by using the keys of the cellular phone. There was a basic navigation set with options "Repeat", "Back" (return to the last visited audionode), and back to "Main page" (see Figure 1). We also experimented with voice only commands, i.e., hyperlinks were integrated at the end of each audionode (e.g., "If you want more information about viruses press button 3") but first formative evaluation and usability studies with students and other researchers (N = 10) revealed that with a growing number of hyperlinks this navigation per audionode was too confusing for learners.

In this study, we developed a non-linear hyperaudio learning environment and a linear version containing the identical audionodes. Whereas in the non-linear program audionodes were associatively linked, the linear program had only a "back & forward"-navigation, realized by key commands provided by the cellular phone interface.

The main purpose of these two prototypes was to investigate the influence of linear vs. non-linear auditory instruction on learning outcomes and measures of cognitive load.

Cognitive Load and Learning with Linear and Non-linear Information Media

A common approach for examining learning processes with linear and non-linear knowledge media is provided by Cognitive Load Theory (CLT; Paas, Renkl, & Sweller, 2004; Sweller, 1994). CLT differentiates between *Intrinsic Cognitive Load* (ICL), *Extraneous Cognitive Load* (ECL) and *Germane Cognitive Load* (GCL; Sweller, van Merriënboer & Paas, 1998). Intrinsic Cognitive Load results from direct information processes and is, thus, not avoidable. Extraneous Cognitive Load is determined by the design of learning material. If the material is appropriately designed for learners' needs, this kind of Cognitive Load will be small. If information is e.g. presented in ambiguous or unclear manner, this kind of load will be increased (e.g., when text and graphics in a text book do not correspond and irritate readers). Germane Cognitive Load is necessary to activate prior knowledge and schemata in order to process new information more deeply.

All three proposed types of Cognitive Load are assumed to be additive. In case of exceeding working memory resources information processing will be decreased thus inhibiting knowledge acquisition (Paas, Tuovinen, Tabbers & Van Greven, 2003). Thus, a basic instructional strategy is to reduce Extraneous Cognitive Load in order to provide capacity for Germane Cognitive Load.

All types of Cognitive Load (CL) sum up to what can be called “Cognitive Overhead” according to Conklin (1987). Given the global assumption of Cognitive Overhead was adequate for hyperaudio, learners should always profit more form linear information presentation than from non-linear sequencing because learning with non-linear (hyper-)audio requires additional mental effort in navigation planning and monitoring. However, Cognitive Load Theory postulates that additional mental effort can also enhance learning, for example, if the additional effort leads to deeper elaboration processes. Despite to critics on the validity of the Cognitive Overhead assumption (e.g., Zumbach, in press), we expected a similar effect of hyperaudio in linear/non-linear comparison as in basic text/hypertext comparisons.

Nevertheless, auditory instruction is quite different from text-based instruction. There are differences in basic assumption related to human working memory and there are differences in empirical findings related to text vs. auditory instruction.

Auditory vs. Text-based Instruction

Auditory instruction is the common way of instruction since the human race is able to express itself by means of language. Research on auditory instruction compared with text-based instruction has started at the beginning of the 20th century (cf. Barron, 2004). The first comparative studies seemed to show an advantage of auditory instruction over text-based instruction. There were, however, many constraints of these early studies like role and behaviour of the reader or shortcomings in data analysis methods. Contemporary research does still present ambiguous outcomes of research on auditory vs. text-based instruction (for an overview see Barron, 2004). Travers (1970, quoted after Barron, 2004, p. 954) states that “One cannot reasonably ask the general question whether the eye of the ear is more efficient for the transmission of information, since clearly some information is better transmitted by on sensory channel than by another”.

Besides this evidence-based research, there are essential contributions provided by cognitive science that are helpful to understand benefits of auditory instruction. Baddeley (1992, 1998) postulates a separate subsystem for auditory information processing in human working memory. Based on Baddeley's assumptions about the human memory, current research explains for example occurrences of the modality effect.

Nevertheless, the empirical and theoretical basis for examining differences of linear vs. non-linear auditory instruction needs much more scientific evidence. Baddeley's theory is here not helpful, because only the phonological subsystem of the working memory is addressed. Furthermore, research on text vs. auditory instruction is ambiguous. Here, Cognitive Load Theory might be able to predict differences in linear vs. non-linear auditory instruction, because navigating and its underlying navigation planning might lead to an increased Extraneous Cognitive Load and, thus, lead to decreased learning performance.

Based on these considerations we tested the following hypotheses:

Hypothesis 1: Navigation planning in non-linear hyperaudio learning environments increases Extraneous Cognitive Load compared with navigation in linear hyperaudio learning environments.

Hypothesis 2: Due to an increased Extraneous Cognitive Load in learning with non-linear hyperaudio learning environments, learning outcomes are worse compared to navigation in linear hyperaudio learning environments.

Method

Design and Sample

In order to test these hypotheses an experiment was conducted comparing non-linear vs. linear hyperaudio. Thirty-two university students majoring in different fields participated in the experiment. There were 10 male and two female equally distributed over both conditions. Participants were randomly assigned to one of the two experimental groups. Each student received € 10 for participation.

Dependent variables

Learning Outcomes: In order to measure individual's learning success a knowledge pre-and post-test was conducted. It included a 12-item multiple-choice test (Cronbach's Alpha = 0.69) and an essay task in order to measure learner's knowledge and understanding. Essay tasks were analysed by a propositional analysis based on the suggestions of Kintsch and van Dijk (1978). Therefore, we compared each proposition in participant's essays with the overall propositions included in the learning material. Each correct correspondence of essay proposition with a proposition in the learning material received one point (this was not a rating but rather a counting).

Cognitive Load: Two instruments assessing Cognitive Load were used in this study: First, the *Mental Effort Rating Scale (MERS;* Paas, van Merriënboer & Adam, 1994). Second, a slightly adapted form of the *NASA-TLX (Task Load Index)* developed by Hart and Staveland (1998). NASA-TLX consists of five subscales each represented by a one-item self-report question (i.e,. t*ask requirements*, *effort in understanding content*, e*xpectation of success*, e*ffort in navigation* and s*tress*). Both measures were used in the post-test (NASA-TLX immediately followed by the MERS). As the NASA-TLX only had an internal consistency of Cronbach's Alpha of 0.48, we dropped one item (Alpha = 0.68) and integrated the MERS-item in order to calculate an overall Cognitive Load value (Cronbach's Alpha of this overall scale was 0.74).

Material

The learning material consisted of a collection of articles in the area of molecular biology. The text material was taken from several articles within the area of bacteria, viruses and genes with their underlying scientific concepts and recorded as audio files. Overall, there were 19 audionodes with spoken 2538 words.

Each audionode was integrated into a computer-based learning environment with either linear or a non-linear navigation access as described above (see Figure 1). The sequence in the linear hyperaudio condition was realized by arranging audionodes in alphabetical order depending on the topic of each node. For the non-linear hyperaudio condition we linked the nodes associatively by using semantic proximity of the nodes. In addition, we added hyperlinks leading to the main page and back to the last visited audionode.

Procedure

The experiment started with oral and written instructions about the task and the handling of the learning programs followed by the pre-test. In the learning phase, participants had 35 minutes to navigate the learning environment provided at single desktop PCs. During this phase, they were not allowed to take notes. Afterwards, they had to complete the post-test with the same essay task and the same multiple-choice test as in the pre-test as well as the NASA-TLX and the MERS. Pre- and post-test lasted each up to 30 minutes.

Results

We found no significant difference in participants prior knowledge related to the domain of the learning environments.

Regarding outcomes, an analysis of variance showed no significant post-test effects. Neither of measures of knowledge acquisition nor cognitive load showed significant differences between both groups (overall: $F(2, 29)=1.28$, $p=0.29$). However, descriptive results showed a higher learning performance of learners in the hyperaudio condition compared with the linear audio condition (see Figure 2).

Hyperaudio led to slightly increased values in Cognitive Load but also to an increased performance in the Multiple-Choice test. An analysis of the percentage of newly acquired propositions revealed a similar result ($F(1, 30)=0.48$; $p=0.49$; see Figure 3).

Table 1 provides an overview on all dependant variables in pre- and post-test.

Summary and Discussion

Research on learning with text and hypertext and its comparison has nowadays a respectable tradition. Nevertheless, research on other non-linear instructional information media like hypervideo or hyperaudio is still at its infancies. In this study, we examined the influence of linear vs. non-linear hyperaudio on learning outcomes by means of Cognitive Load Theory and measures of knowledge acquisition. Results do not confirm the hypothesized effect stating that non-linear hyperaudio leads to increased Cognitive Load and decreased knowledge acquisition compared to linear presentation of the same information. In contrast, results provide first evidence, that learning with hyperaudio and learning with linear audio in comparison to their text-based counterparts render different results. Thus, comparative research from text vs. hypertext studies cannot be generalized to linear audio vs. hyperaudio learning environments.

We found in this study a neglectable difference in self-reported measures of Cognitive Load. Due to the requirement of navigation in both conditions (though the navigation in the hyperaudio condition was much more complex) and the unusual information media, Cognitive Load was measured as fairly high. As the interface was consistent over both conditions, it might be that the cellular phone visualisation accompanied with the unusual information retrieval caused an Extraneous Cognitive Load per se occupying most available resources. In contrast, auditory memory might be able to compensate for problems deriving from issues of navigation planning.

Descriptive results in both measures of knowledge acquisition revealed a slight advantage of the hyperaudio learning scenarios. A possible explanation for this effect might be the complexity of the learning material. Possibly, the non-linear presentation of this loosely structured information was the better presentation format.

Taken together, results show that hyperaudio might be a promising way of delivering non-linear information to learners without the disadvantages of non-linear written information media. The technology for this kind of information distribution is in almost everyone's pocket. This is also the reason why we chose here this kind of interface: it is ecological valid and could be implemented on existing cellular phone hardware. As these investigations are still in their infancy, further research from a technical and a psychological perspective is needed.

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Table 1: Means and Standard Deviations of Learning Outcomes and Cognitive Load

	Experimental Treatment							
	Pre-Test Linear Audio (n=17)		Pre-Test Hyperaudio (n=15)		Post-Test Linear Audio (n=17)		Post-Test Hyperaudio (n=15)	
Dependent Variables	M	SD	M	SD	M	SD	M	SD
Multiple Choice	3.24	2.4	4.07	2.28	6.59	2.9	7.47	1.85
Propositions %	0.6	0.6	1.14	0.9	4.94	2.6	6.07	2.65
Cognitive Load	N/A	N/A	N/A	N/A	5.62	1.51	6.18	1.44

Figure 1: Prototype of a hyperaudio learning environment application running on a cellular phone

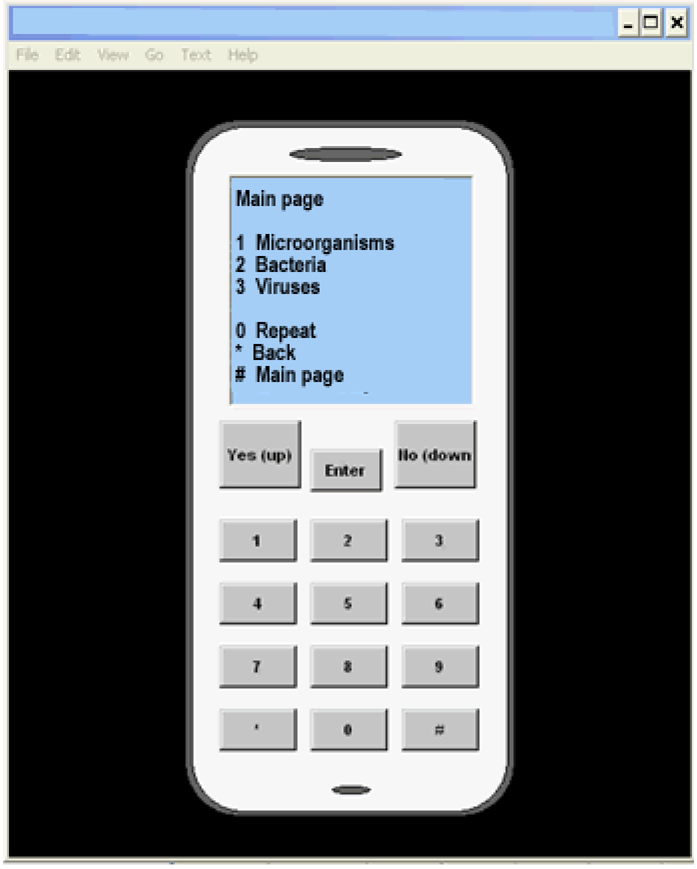

Figure 2: Outcomes in Cognitive Load and Knowledge Acquisition

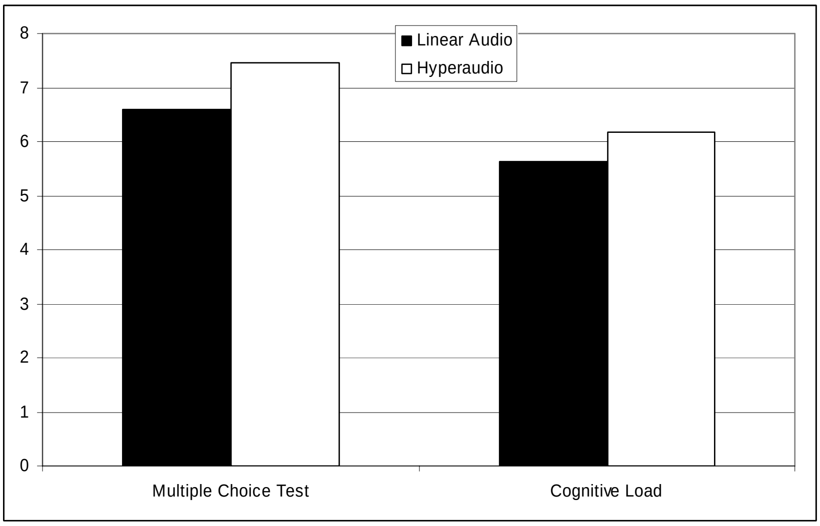

Figure 3: Results in percentage of newly acquired propositions comparing pre-test and post-test essay