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Modeling, design, development and evaluation of a hypervideo presentation for digital systems teaching and learning

**Samra Mujacic · Matjaz Debevc · Primoz Kosec ·
Marcus Bloice · Andreas Holzinger**

Abstract Hypervideos are multimedia files, which differ from traditional video files in that they can be navigated by using links that are embedded in them. Students can therefore easily access content that explains and clarifies certain points of the lectures that are difficult to understand, while at the same time not interrupting the flow of the original video presentation. In this paper we report on the design, development and evaluation of a hypermedia e-Learning tool for university students. First, the structure of the hypervideo model is presented; once the structure is known, the process of creating hypervideo content is described in detail, as are the various ways in which content can be linked together. Finally, an evaluation is presented, which has been carried out in the context of an engineering class by use of an interactive experiment, involving $N=88$ students from a digital systems course. In this study the students were randomly assigned to two groups; one group participated in the course as usual, whilst the second group participated in the same course while also combining the conventional learning with the hypervideo content developed for the course. The students' learning

S. Mujacic
Faculty of Electrical Engineering & University Centre for Distance Education Development,
University of Tuzla, Tuzla, Bosnia and Herzegovina
e-mail: samra.mujacic@untz.ba

M. Debevc · P. Kosec
Faculty of Electrical Engineering and Computer Science, University of Maribor, Maribor, Slovenia

M. Debevc
e-mail: matjaz.debevc@uni-mb.si

P. Kosec
e-mail: pkosec@uni-mb.si

M. Bloice · A. Holzinger (✉)
Research Unit HCI4MED, Institute of Medical Informatics, Statistics and Documentation,
Institute of Information Systems and Computer Media and Graz University of Technology,
Medical University Graz, Auenbruggerplatz 2/V, 8036 Graz, Austria
e-mail: andreas.holzinger@medunigraz.at

M. Bloice
e-mail: marcus.bloice@medunigraz.at

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results showed that the students who had access to the hypervideo content performed significantly better than the comparison group.

Keywords Hypervideo · e-Learning · Multimedia service · Navigation · SMIL

1 Introduction

Web technology provides many different sources and types of information, as well as many ways to communicate either off-line or live. In essence, it diminishes traditional temporal and spatial obstacles [11]. Hypermedia, or multimedia hypertext, the core of web technology, is the basic element that interlinks the nodes that contain all the different types of media, such as text, graphics, video, and sound on the Internet [15]. It is a tool for the structural presentation and distribution of information which has evolved from being a simple, dynamic, hypertext enhanced medium to a fully-integrated, ubiquitous information system consisting of a huge amount of highly interlinked media. As such, hypermedia has also become an extremely useful tool for distance learning [8].

As the bandwidth of typical Internet connections increases, so does the use of video materials. And, as recent research suggests, video-based lecturing is one of the most powerful and information-rich forms of distance lecturing [40]. Evidence also suggests that using video lectures to enhance distance learning creates a more effective environment and learning experience than simple text or graphics alone [26, 39]. Previous research has also shown that the act of presenting learning content has a significant impact on learning performance [22]. It has long been assumed that dynamic media might be the most successful method for presenting learning content about complex dynamic systems, such as blood flow or how combustion engines function, etc. Such dynamic media can indeed significantly facilitate learning; however, past research has also yielded inconsistent and sometimes contradictory effects [31]. Therefore, factors such as usability, enjoyment, and most of all the didactical setting, should also be taken into account [23, 25].

The next evolutionary step in long distance learning is the use of hypervideo, a video stream that contains links to other media, such as text, figures, other sounds or other videos [3, 29, 37, 38]. Hypervideo is navigated in a very similar way to hypertext, and the procedure adheres almost exactly to the Dexter hypertext definitions [15]. They offer users a path to follow by providing short narratives of what lies ahead and reviews of what came before.

The most important difference between classic hypermedia systems and hypervideo is that hypervideo links are not static; rather, links to objects appear and disappear with time as the video sequences play out.

One question that is discussed throughout the paper is whether this concept of *time-limited hyperlinks* could be used for distance-learning. More specifically, whether it could be used in electrical engineering courses where many practical and direct interactions with various systems are required beyond the standard theoretical instruction. In standard distance learning, video is mainly used for taping lectures, and the video is then placed on the course's web page as video-on-demand. Generally speaking, electrical engineering courses include experiments that are performed in labs. Students would benefit from having these experiments available for later viewing. We therefore created a prototype of an experiment, and later evaluated whether the experiment provided sufficient information for the students to fully understand the subject.

The following approach was taken during the course of writing the paper:

- Definitions were provided for the basic design principles of the hypervideo project. For example, access to segments, object timing, and navigation.
- Possible ways of creating rich media presentations with video for students of electrical engineering were provided. As an example, the structure and development procedure of several hypervideo presentations for a Digital Systems course were provided. For the implementation of the hypervideo presentations, the SMIL 2.0 markup language (Synchronized Multimedia Integration Language) [5, 36], and the Grins Editor for SMIL 2.0 authoring tool were used [14].
- Two different approaches were implemented in order to achieve the most reliable data about the effectiveness, usability, and usefulness of the application in question, and these results were analyzed. The first approach used summative analyses of the passing rate and average grade, using Statistica 5.0 [42], while the second approach was based on formative analyses, using a questionnaire, which was modified as per the proposals in [1, 24].

The results of these evaluations provided some constructive ideas for improving the hypervideo presentation, which are discussed in detail in a further section.

2 Background and related work

2.1 The hypervideo presentation

Video-to-video linking was first demonstrated in the Elastic Charles project, presented in a hypermedia journal [4], and developed by the Interactive Cinema Group at the MIT Media Lab. The term hypervideo was first proposed by the creators of Hypercafe [37], which was an experimental hypermedia project developed in order to illustrate general hypervideo concepts. Hyper-textual elements are present in the form of explanatory text, complementary subtitles, and intruding narratives. Hypercafe was followed by several other applications, such as HyperSoap [10], the Networked Hyper QuickTime prototype [30], and the approach described by [13]. The synchronization of media within hypermedia documents has also been widely researched, as for instance in the Amsterdam Hypermedia Model—AHM [16, 19], and from work carried out by [17, 21]. In the area of distance learning, hypervideo is part of Chambel and Guimaraes' Unibase Project [7]. The Vox Populi system [46] is also used for educational purposes [2].

The approach undertaken for this project used the design aspects and structures, mentioned above, while extending the synchronization, interactivity, and adaptability of previous work. Our main focus was on the viewer's experience, which is generated by navigating and interacting with the video that contains narrative and textual guidance. In addition, our hypervideo approach allows the content's presentation to be customized according to the end user's available bandwidth. The preferred language used by the audio track or textual documents can also be altered. Therefore, the adaptation and customization of the hypermedia content is enabled at the user level and the system level.

2.2 Hypervideo presentation authoring tools

The SMIL 2.0 specification, which was released by the World Wide Web Consortium (W3C) in August 2001, was chosen for this work. This standard specifies a collection of modules that describe the possibilities for integrating and scheduling media objects (in their most general form) for their presentation in local and network-based environments [47]. SMIL's focus is not on data encoding; rather, it focuses on media integration and specifies how components relate temporally and spatially during their presentation [5, 47].

To aid development, there are several tools available that can be used to create SMIL hypervideo presentations, for example: the Veon V-Active software tool [45], MediaLoom [44], the HyperProp system [41], SMILAuthor [48], and Microsoft Media Producer [32]. Perhaps the most well know tool of this kind is the Grins Editor [14], which includes a graphical interface for the creation and playback of SMIL documents. Therefore, for the purpose of this paper, the Grins Editor for SMIL 2.0 was chosen to create the test hypervideo presentation. Hypervideo presentations created by Grins can be viewed by using the RealOne player [34].

Furthermore, the Grins Editor supports the integration of multiple forms of media, allows the application's code to quickly be edited, and can simplify the behavior of the hypervideos created.

3 Quality description of hypermedia documents

Document structure is a central concept for the creation, and especially for the use of, complex hypermedia documents. In previous research these concepts have been formalized and expressed as hypermedia models [13]. Some of these key concepts are described in the following sections, in order to provide an overview of what they entail.

3.1 Multimedia to hypervideo transformation

Multimedia documents contain various types of objects: text, graphics, images, animations, voice, and videos, among others. These objects and their compositions are called multimedia objects.

Multimedia documents with hypermedia elements (hypermedia documents) can be described using four dimensions, as stated in Layaida [28]:

- The logical dimension is defined by the complete logical organization of the information contained in a document.
- The spatial dimension refers to the presentation of various document elements via their corresponding presentation media types (display, audio channel, etc.)
- The hypermedia dimension defines relation-links between elements and parts, or sections, of documents. Hypervideo documents can further be described in the hypermedia dimension, which defines dynamic links within continuous media. Therefore they possess dimensions of both time and space.
- The temporal dimension defines the temporal organization of elements.

The aim of hypermedia is to structure and organize information. Hypermedia presents a good way of providing this structure and allows for the interaction with hypermedia information. Different approaches to hypermedia content design, developed for the various levels of freedom required by the students, enable alterations for different situations and study styles, as shown in Hardman [12, 18, 20, 27, 33]. Currently hypervideo is one of the most advanced uses of video for distance learning. Hypervideo can be described as interactive video, where interactive elements are contained within the streaming video, and act like hyperlinks to other content, similar to the way text and images are used as hyperlinks in web pages [37].

3.2 Hypervideo structure

In video-centered media, the temporal and spatial aspects of the content must be considered. The creation of this media requires that the designer is able to design a story through both video and text which changes dynamically over time. For this purpose a number of elements are available to the designer to enable hypervideo production, and are described in the following section.

3.2.1 Elements

This section describes the various elements that constitute a hypervideo document.

Scene	the smallest unit of hypervideo content. It is constructed using a set of sequentially presented digital video frames.
Narrative sequence	a possible path or tree for a group of related videos and synchronized hypertext. This is sometimes dynamically attached to a user's interaction or to the scene content.
Temporal links	time-based references between two video scenes, where new video scenes are activated at certain moments during the source video.
Space-temporal links	references between different video scenes, where specified spatial locations within the source video scene activate new video scenes at certain moments.
Navigation	static elements that are always available to the user. Hypervideo links can only be activated by the user within defined intervals of time.

3.2.2 Synchronization primitives

To properly explain what synchronization primitives are, the relationships which determine the way in which the document is delivered and presented to the user needs to be defined. Hypermedia documents can be treated as a group of objects of different types (videos, sounds, textual pages or photos), where each type has its own role during the presentation. Each object needs to be added to a corresponding channel in order to be shown. Some objects share the same channel, but at different time intervals.

It is, therefore, required to define their relationships with the goal of modeling each object's behavior and channel usage via synchronization primitives.

In order to define the concept of hypervideo synchronization frames, the model described in Layaida [28] is used, where five such synchronization primitives are defined.

For the purposes of this work, and to fully explain their use in hypervideo documents, another synchronization primitive has been added. A hypervideo document can therefore be described, with use of the additional element $A\Delta t\leftrightarrow B$, as follows:

- B acts with A ($A\leftrightarrow B$)

Suppose that A and B are general media objects. The definition "B acts with A" refers to the relation where the activation of object A causes the activation of object B and the natural end of first object forces the second object to end. This relation describes two elements shown in parallel.

- B acts with A after time distance Δt ($A\Delta t\leftrightarrow B$)

Suppose A and B are general media objects. The definition "B acts with A after time distance Δt" refers to a relation where the activation of object A causes the activation of object B after a certain time delay Δt, and the natural end of the first object forces the second object to end. This synchronization primitive can be treated as a special case of the previously defined primitive.

- A activates B (A→B)

Suppose A and B are general media objects. The definition “A activates B” describes a situation where the natural end of object A causes the beginning of object B’s presentation. This relation describes two objects shown in sequence.

- B ends with A (A↓B)

Suppose A and B are general media objects. The definition “B ends with A” describes a relation where the forced ending of object A causes the forced ending of object B. The channels which are used by these two objects are released after this action.

- A is replaced by B (A↕B)

Suppose A and B are general media objects of the same type. The definition “A is replaced by B” describes a situation where the activation of object B forces the ending of object A. The channel used by A until this event is free to be used by object B.

- A has priority over B with action α (Aα⇒B)

Suppose A and B are general media objects. The definition “A has priority over B with action α” describes a relation where the activation of object A (either by the user or by presentation design) forces object B to release the channel that it has been using so that object A can use it. The label α denotes the behavior of object B when the channel is being freed. The value of α can be one of two values, p or s. If α=p, then object B is forced to stop and enter an inactive state (it is paused); if α=s, then object B is forced to end (it is stopped), releasing used resources. A special case of priority behavior where α=c enables the concurrent running of both objects, where each presentation must be shown in a separate window.

3.2.3 Adaptive and adaptable hypermedia presentations

Adaptive hypermedia presentations are presentations that adapt automatically according to certain parameters; they offer alternatives to individual parts of the presentation, based on directives contained in the definition of the presentation. Several approaches exist that enable additional content to be added to the presentation, and these approaches can be split into two main subgroups: the declarative-based approach, and the program-based approach [6]. Program-based control is the most obvious form of adaptive control. It is based on a program or script directive within the document that analyses the current situation and executes which choice to make for each published request for data. Alternatives are explicitly defined in the presentation. This approach is used in HTML 4.0, often called dynamic HTML. SMIL, used here for the development of adaptive hypermedia presentations, introduces the adaptive approach by using “switch” elements. Switch elements allow the specification of multiple alternatives for content presentation, while only one is chosen based on certain conditions.

Adaptable hypermedia, on the other hand, offers adaptation using directives that are not part of the basic definition of the presentation. The adaptable approach displays one large frame that entirely covers the presentation. This usually requires external processing; the aim being to enable the implementation of interchanges in presentation semantics.

The distinction between adaptive and adaptable presentations is differentiated by the level of adaption process autonomy. Upon processing the presentation for the end-user, both types of adaption in hypermedia documents consider various circumstances, such as user and content characteristics. In general, adaptable hypermedia is more diverse than adaptive hypermedia; however it requires more complex processing in order to enable presentation transformation.

4 An example hypervideo presentation development scenario

Once a structure had been defined, hypervideo learning material was developed for the students of the Digital Systems course (on-line laboratory section: pre-lab and post-lab activities and content). The hypermedia presentation of the laboratory exercises introduces the process of schematics-based component connection. This is presented in the “Half-adder and full-adder” example. Students may follow the process of scheme conjunction, experiment execution, and obtain their results for each conjunction scheme for both laboratory models. They also have the opportunity to activate the space-temporal video links within these videos and view them as continuous media (see Fig. 2).

As well as this, the presentation of the hypermedia content can be adjusted according to the user’s configuration attributes. Adjustments include the speed of the user’s Internet connection, or the selected language. In this way, learning content can be adapted at the point where the hypervideo presentations are created.

4.1 Design of an example hypervideo presentation

The first step when developing a hypervideo presentation is to create a detailed and complete design. All the scenes need to be prepared, all the narrative sequences planned, and all possible navigation, as well as the spatial and temporal arrangement of its elements, must be defined. The synchronization frame of the hypervideo presentation is defined using synchronization primitives, as shown in Fig. 1a and b.

Adaptability is also enabled on a structural level by testing certain attributes, such as the bandwidth or language, and by using SMIL switch elements to alter them. In the Tst2 scenario, PIP (Picture in Picture) video used in the Tst1 scenario is swapped with static images due to the low available bandwidth.

Media element v1 presents a video sequence of the complete laboratory exercise (two conjunction schemes) using the first laboratory kit, while v2 and v3 present video sequences of the same scheme conjunction, but using the second laboratory kit, as in Fig. 1a. Elements a1, a2, and a3 present corresponding audio sequences, while textual elements t1 and t2 serve to inform the student about the possibility of activating the hyperlinks. The presentation begins with the synchronization of both the v1 and a1 elements, as shown in the figure. After $\Delta t1$ time, the student is informed (via sound, text and PIP video (v2)) within the main video stream that hypervideo elements can be activated.

If the student activates the hypervideo link, a new window is opened and video v2 is shown, while video v1 is paused in the background. After the v2 video stream has finished, the student can close the window and continue watching the v1 stream. A similar scenario is used for the activation of the v3 video stream.

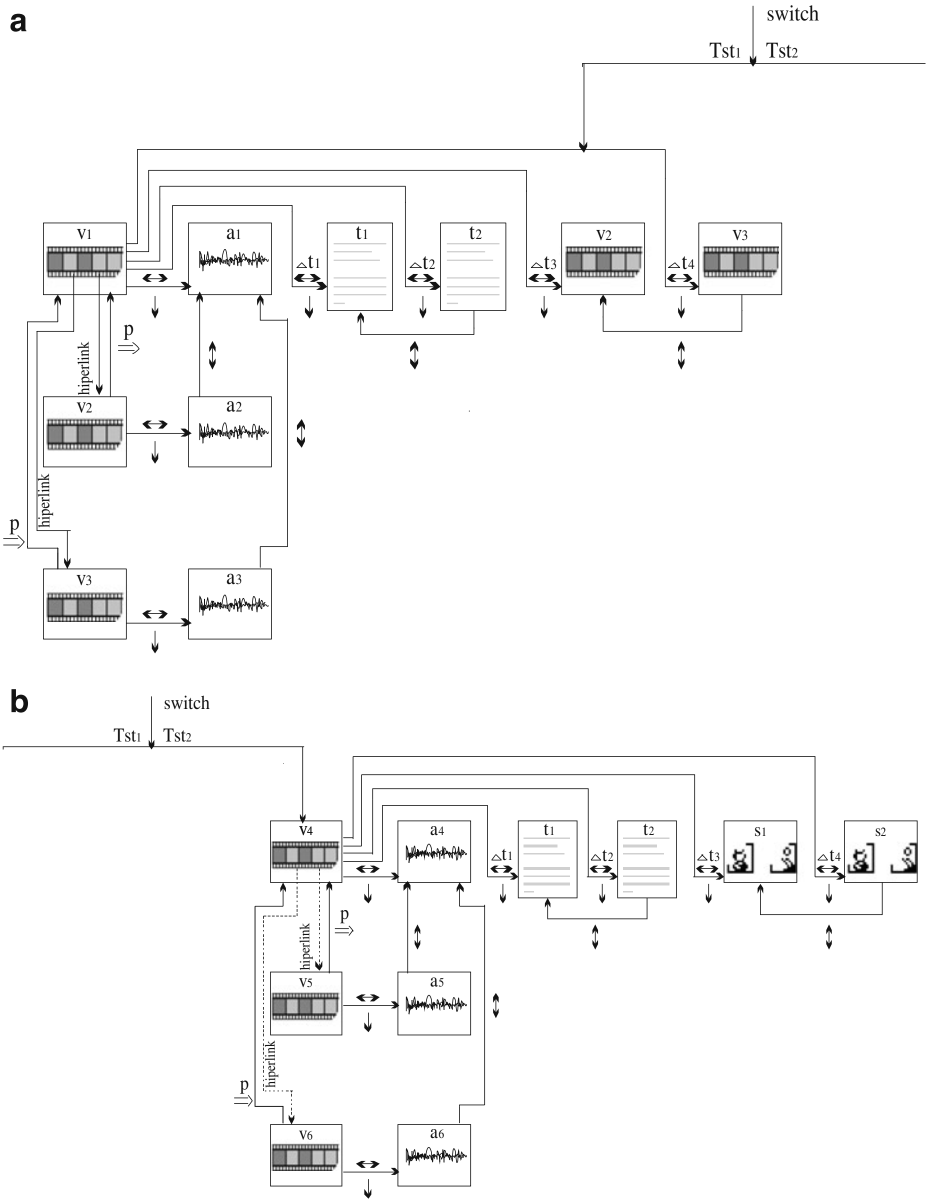


Fig. 1 **a**: Synchronization framework for the hypervideo presentation prototype: Tst1 scenario (student's bandwidth 150 kbps and above). **b**: Synchronization framework for the hypervideo presentation prototype: Tst2 scenario (student's bandwidth less than 56 kbps)

4.2 Implementation of an example hypervideo presentation

The scenario proposed above was implemented as follows:

A digital camera was used to record the video and audio content. The handling and preparation of the separate content elements (video, audio, text, etc.) was produced using

RealNetworks' Production Bundle software [35]. The integration of all the components into a single hypervideo presentation was performed using the Grins Editor for SMIL 2.0 [14].

The following aspects of the hypermedia document were defined:

- The time dimension: this starts with the creation of the time containers par and seq (time containers are defined in the SMIL 2.0 specification).
- The spatial dimension: performed by using Grins' layout option, which allows for the graphical configuration and positioning of spatial frameworks for a particular content.
- Adaptability: performed at the level of user's Internet access bandwidth (56 kbps, 150 kbps, and above) and preferred language, and is embedded in the SMIL switch element.
- The creation and synchronization of the hyperlinks using Grins' hyperlinks option, where the spatial and temporal characteristics of the source and destination hypervideos are defined, as well as the behavior of the source video after the activation of the hypervideo link.

The most demanding step during the development of the hypermedia document is the creation and synchronization of hypervideo links, and the adaptation of the content according to defined user and system attributes. For each planned scenario, based on the previously defined attributes, the appropriate switch element within the SMIL document had to be created.

The code generated can be reviewed at any time and manually corrected using Grins' source option. Any hypervideo presentations developed can be delivered over the Internet or on CD. Any documents produced can be viewed with the freely available RealOne Player.

Figure 2 shows the outlook of a hypervideo presentation at the moment of possible hypervideo link appearance (left frame) and after the user interaction with the hypervideo content (right frame).

5 Evaluation

Hypervideo learning content is central to the hypermedia model for the combined learning method used for the Digital Systems course. This model was used alongside the traditional learning methods. Therefore, the hypermedia model can be compared to the classical, traditional learning model.

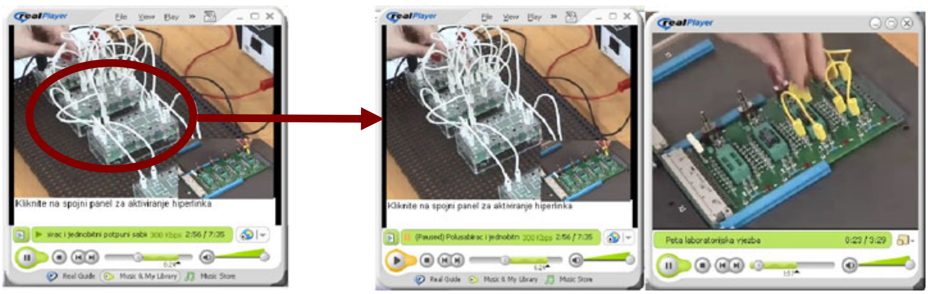


Fig. 2 Presentation outlook after the hypervideo link appearance and activation

[9, 43] list various approaches for evaluating the results that were obtained, and for the purposes of this work the point evaluation method was chosen. This means that the evaluation was performed in three steps:

1) Preparation
   The preparation phase evaluates the knowledge that the students gained after the written exams.
2) Results assessment
   This phase involved the students from group two having to complete a questionnaire
3) Final evaluation
   The students' answers were analyzed during the evaluation phase. Summative and diagnostic methods were used to gauge what the students had learned, and to assess the quality of the hypermedia model that was created.

$N=88$ students were randomly split into two test groups of 44 students each, all of whom were enrolled in the course for the first time. Group A, the control group, undertook the course using the traditional learning model of lectures and lab work. Group B, the test group, used the hypermedia model in conjunction with the traditional learning techniques.

The effectiveness of the hypermedia model was assessed by the students' exam performance. A formal analysis based on the following data was also performed for both groups:

- Summative evaluation
- Students' achievements during the colloquia (two per semester)
- Students' achievements for all exams during the academic year
- Percentage of exams passed after the last exam during the academic year
- Percentage of students who took part in the exams
- Formative evaluation
- Results of the questionnaire that was completed by the students of the second test group.

5.1 Summative analysis of the hypermedia model

A student is considered to have passed an exam if he or she either passes both colloquia that take place once each during the ongoing semester, or if he or she passes any exam that takes place after the lectures finish.

Students are graded for their exams on a scale of 0–100. A student is considered to have passed an exam if their result is 50 points or over. A student also passes an exam if their result for both colloquia is at least 50 points. The final result for both colloquia is calculated as a mean value of the points achieved for each colloquium. All of the exam and colloquium terms in one academic year for both groups were included in the analysis.

The data was sorted and analyzed using Statistica 5.0 by StatSoft, Inc. [42].

5.1.1 Testing the statistical variables for the student test groups

The first step of our evaluation was to analyze the students' exam pass rates in both groups after all exam terms in the academic year were complete. In group A, the number of students that passed their exams was 19, while this number was 38 in group B (out of 44 in each group). This represents a significant statistical difference; $t(87)=4.543$ ($p<0.0001$).

Using the same technique, the results for the colloquia and for each single exam term was analyzed. Table 1 shows that significantly more students in group B than in group A passed both the first (t(87)=2.747, $p<0.01$) and the second colloquium (t(87)=3.616, $p<0.01$).

Even when disregarding students who passed their exams with help from their colloquia, the result can be treated as significant, with a p value of 0.0150. Significantly fewer students in group B failed to attend the exams or colloquia. The increased motivation for group B to attend their exams is clear. There was no significant difference between the groups regarding the proportion of students who passed the first colloquium or the proportion of students who failed to attend the second colloquium. However, there was a non-significant trend for more students in group A to skip the second colloquium.

Most importantly, Table 1 shows that the performance of group B for both the colloquia and the regular exams was consistently and significantly superior to group A.

5.1.2 Testing the mean and standard deviation of the students' grades

In addition to the analysis explained in section 5.1.1, we evaluated the difference between the mean overall grades for groups A and B, as well as the differences between the groups for individual colloquium scores. We also examined the variability of the scores between the two groups, and tested the assumption of a normal distribution of scores.

The analysis shows that group B scored significantly better course grades (including the colloquia grades), except for the first colloquium (for the first colloquium, certain students in group B obtained scores that were relatively lower than what they received for the

Table 1 Statistical comparison of student groups A and B: colloquium and exam performance

Groups / Exams		Degree of freedom	t value
Group A	Group B		
I colloquium—passed		87	**0.9942
24/44	36/44		
II colloquium—passed		87	**0.9996
13/44	30/44		
After all terms—passed		44	*0.9881
6/31	8/14		
Total colloquiums and exam terms—passed		87	**0.9999
19/44	38/44		
I colloquium—not passed		70	0,7107
6/30	5/41		
II colloquium—not passed		53	**0.9999
11/24	0/30		
I colloquium—not attended		87	**0.9969
14/44	3/44		
II colloquium—not attended		87	0,8478
20/44	14/44		
After all exam terms—not passed or not attended		44	*0.9881
25/31	6/14		

*$p<0.05$ **$p<0.01$

second colloquium). Furthermore, the variability of the scores for the two groups appears to be comparable, with a somewhat lower variability for group B.

The mean and standard errors of the scores of the two groups can be graphically illustrated with Box-Whisker graphs, as shown in Fig. 3 for the same exams. The small squares on these graphs represent the mean values, while the rectangles represent the standard error boundaries, and the final boundary lines represent the standard deviations.

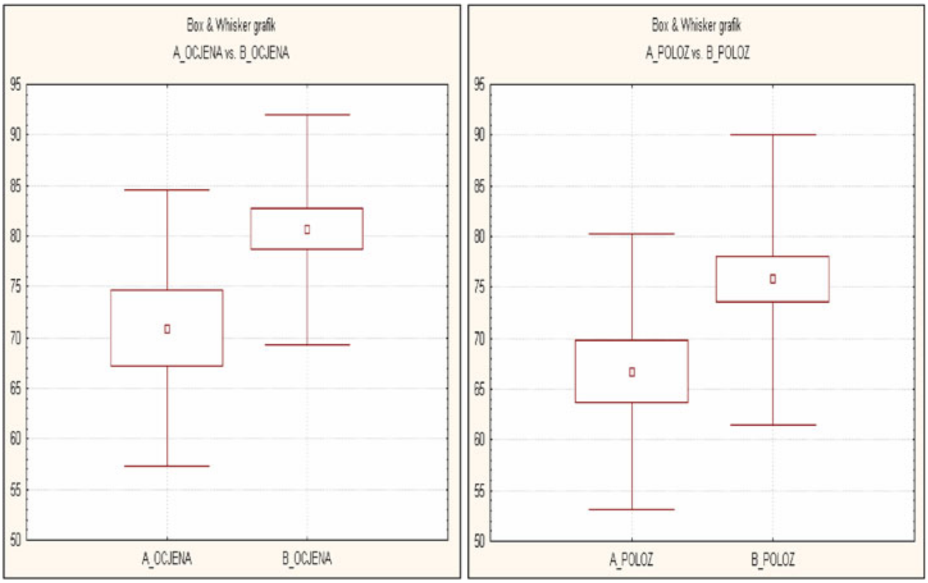
Note that Group B's significantly better rate of passing exams, described in section 5.1.1, is not shown in these graphs.

The test of the normal distribution of the exam results was done using a Kolmogorov-Smirnov test, the Liliefors modification, and the Shapiro-Wilk's W test. The Kolmogorov-Smirnov test confirmed that the grades were normally distributed. The Liliefors modification confirms a normal distribution except for <B_KOLOK> (Bosnian: Colloquium, group B) and <KOLOKVIJ> (Colloquium, collective). The Shapiro-Wilk test could only reject the hypothesis of normal distribution for the variables <KOLOKVIJ>, and in some instances <B_KOLOK>, shown in Table 2. Therefore, the assumption that the analyzed variables were normally distributed was confirmed.

Taken as a whole, the quantitative analysis of colloquium scores, course grades, and rates of passing exams show that group B consistently and significantly outperformed group A. The fact that both groups were given the same standard teaching material, and that the same teacher lectured both groups, would suggest that the superior performance of group B can be attributed to their use of the hypermedia model.

5.2 Formative analysis of the hypermedia model

Questionnaires were administered to the students in group B for the qualitative analysis.



Legend: OCJENA = Colloquium (collective) grade per group; POLOZ = overall course grade per group

Fig. 3 Colloquium (collective) and overall course grade comparison for groups A and B

Table 2 Shapiro-Wilk test

Shapiro-Wilk W test			
Variable	Mean and standard deviation estimated from data		
	N	W	p
A_grade	13	0.91644	0.216743
B_grade	30	0.966137	0.486239
A_passed	19	0.911380	0.080443
B_passed	38	0.947927	0.104279
A_colloq	54	0.960253	0.136678
B_colloq	66	0.919899	0.000257
Colloquium	120	0.934859	0.000007

The questionnaire evaluated the hypermedia learning model, its individual modules, and its value relative to the classical learning model. For this reason, students from group A did not participate. The questionnaire was a modified version of the questionnaire used by Barua [1, 24].

The results obtained from the questionnaire are as follows:

- 69.23% of students completely agreed with the statement that the model simplifies laboratory work, while 30.77% of students agreed, while none of the students disagreed. Therefore, the students' answers would tend to confirm the effectiveness of the learning model provided by the hypermedia content. The mean value for this question was 1.308, which falls into the "completely agree" answer group.
- Every student (84.62% answering with "completely agree" and 15.38% answering with "agree") positively evaluated the on-line laboratory section of the learning course (pre-lab and post-lab content and activities which included hypervideo presentations). The on-line laboratory module is considered an efficient and productive learning tool, and was rated the best module in the questionnaire. The mean value for this question was 1.154, which falls into the "completely agree" category.
- 23.08% of students completely agreed and 46.15% of them agreed that the interaction with the model was clear, useful and efficient. 7.69% of students disagreed with this statement. The mean value for this question is 2.154 and corresponds to "agree".

The results of the questionnaire show highly positive results for the qualitative evaluation of the chosen hypermedia model by group B students with regard to its usefulness and effectiveness, with the majority of answers of type "agree" or "completely agree".

6 Conclusions

To demonstrate the hypervideo generation process, a prototype of an interactive, adaptive, hypermedia-based, video-centered presentation was developed based on the SMIL 2.0 specification. The prototype featured structured, video-based scenes that allowed the students to interact with the content and also included some basic adaptive elements. The work carried out focused on the raised level of user experience, by allowing the students to navigate and interact with the video or textual content.

The efficiency analysis of the hypermedia model was performed using a summative and formative analysis of the student test groups A and B. Students from group A took the Digital Systems course using the classical learning model of lectures and labs, while students from group B were taught using the hypermedia model along with the classical model. The results of summative analysis have led us to conclude that groups A and B received significantly different grades; the students from group B receiving the higher average grade. Furthermore, the variability of the students' grades was not large, with group B having a slightly lower standard deviation than group A. In other words, the students' grades did not deviate from the mean grade by very much.

However, the most telling difference between the two groups was that 19 students from group A passed in comparison to 38 from group B.

By interviewing the students, it was possible to see that the introduction of the hypervideo content provided during the on-line laboratory section gave them a better insight into the experiments that were performed in the laboratory, and enabled a higher level of interaction and control over the content offered.

Students did express a certain level of concern after their first experiences with using the hypervideo content, due to a lack of familiarity with navigating through the hypervideo content. However, by keeping the same basic structure consistent throughout all the hypervideo documents, this was not a significant problem after some time.

Future work will focus on improving of the hypermedia content, primarily from the aspect of distance learning didactics: by utilizing a sequence of tests and evaluations, the structure of the hypervideo learning content will be defined, which will increase the quality of knowledge gained when using the hypermedia technology. The introduction of another level of adaptability, based on user characteristics, would lead to significantly advancing adaptation control. Also, a voting system is being considered as a future feature for the system. This would allow students, who watch the lectures, to vote for parts of the lecture they found difficult to understand or that needed further explanation. The teacher would then be able to add hyperlinks to these sections of the lecture where many students seemed to have the most difficulty in understanding the content.

As for the students' results, the reasons for the second group's improved grades must also be discussed. Specifically, it would be of interest to deliberate as to how and why hypervideo enhances learning as opposed to standard video content, or indeed courses with no video content at all. This opens an entirely separate area of research that is not within the scope of this paper, and will therefore be the subject of future work.

In addition, a "black-box" evaluation of the hypervideo-based teaching approach and other similar approaches would be very informative, and will constitute further work that will be performed.

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Samra Mujačić received her PhD in technical sciences from the Faculty of Electrical Engineering and Computing in Zagreb, Croatia. Currently, she is head of the University Centre for Distance Education Development and Assistant Professor at the Faculty of Electrical Engineering, University of Tuzla. Her professional interests include e-Learning, multimedia systems, communications and adaptive hypermedia. She has worked in 20+ research projects and published two books and numerous scientific publications. She was co-author of the National Strategy for Information Society Development and is vice-president of BHITS, and secretary member of the e-Learning Task Force.

Matjaž Debevc received his PhD in computer sciences from the University of Maribor, Slovenia in 1995. Currently, he is an associate professor at the Faculty of Electrical engineering and computer sciences at the same university. From 1999 until 2003, he was the head of the Centre for Distance Education Development at the University of Maribor and often serves as a consultant for educational technologies. His professional interests include human-computer interaction, user interface design, adaptive user interfaces, internet applications and distance education. Dr. Matjaž Debevc has received an UNESCO award for his work in human-computer interaction and SOCRATES COMENIUS award for e-learning.

Primož Kosec received his BSc in Computer Science from the University of Maribor, Faculty of Electrical Engineering and Computer Science. Afterwards he joined the Institute of Automation at the same University and started his research doctorate in telecommunications. He is also a teaching assistant for the field Computer Science. His professional interests include designing and implementing Web applications; however, the last few years he has been prioritizing usability engineering. His current interests focus on implementing and evaluating applications for deaf and hard of hearing web users.

Marcus Bloice completed and received his BSc and MSc in Information Technology from the University of Sunderland. Currently he is working with the Research Unit HCI4MED at the Institute for Medical Informatics, Graz and is studying for his PhD under the supervision of Prof. Holzinger. His current research interests include electronic patient records, medical documentation and Information Systems generally.

Andreas Holzinger is head of the Research Unit HCI4MED, Medical University Graz and Associate Professor of Applied Informatics at Graz University of Technology, Institute of Information Systems and Computer Media. He is chair of the WG HCI&UE of the Austrian Computer Society and Austrian delegate in IFIP TC 13 HCI. He was Visiting Professor in Berlin, Innsbruck, Vienna and London and serves as consultant for the Austrian, German and Dutch government and for the European Union. His mission is in research & development and consulting to realize easier, simpler and faster usable Multimedia Information Systems with a strong commitment to Human-Centered Design, see http://hci4all.at