Adaptive Navigation Support in Educational Hypermedia: An Evaluation of the ISIS-Tutor

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Summary: Adaptive navigation support (ANS) is a new direction of research within the area of adaptive interfaces. The goal of ANS techniques is to help users find an appropriate path in the learning and information space by adapting link presentation to the goals, knowledge, and other characteristics of an individual user. This paper is devoted to evaluation of adaptive navigation support in educational context. We present an educational hypermedia system ISIS-Tutor that applies several ANS technologies -- adaptive annotation, adaptive hiding, and direct guidance -- and describe a study, which evaluates the first two technologies. The results show that adaptive navigation support is helpful and can reduce user navigation efforts.

Keywords: adaptive hypermedia, navigation support, educational hypermedia, intelligent tutoring systems, student model

1 Introduction

The use of adaptive hypermedia systems is one of the ways of increasing the functionality of hypermedia. Adaptive hypermedia systems build a model of the goals, preferences and knowledge of the individual user and use this throughout the interaction for adaptation to the needs of that user. Adaptive hypermedia can be useful in any situation when the system is expected to be used by people with different goals and knowledge, where the hyperspace is reasonably big, or where the system can successfully guide the user in his or her work (P. Brusilovsky, 1996). Education is one of the most promising application areas for adaptive hypermedia. Adaptive hypermedia can be applied here for all the above reasons to adapt the presented information to the current knowledge level of the student, to provide navigation support, and to guide the student in the learning process.

There are two general ways of adaptation in adaptive hypermedia: *adaptive presentation* (or content-level adaptation) and *adaptive navigation support* (or link-level adaptation). Adaptive presentation is the most studied way of hypermedia adaptation (I. Beaumont, 1994; C. Boyle & A. O. Encarnacion, 1994). The idea of adaptive presentation is to adapt the content of a page to the knowledge, goals, and other features of an individual user. With adaptive presentation the content of a hypermedia page is individually generated or assembled from pieces for each user. Generally, qualified users receive more detailed and deep information, while novices receive more additional explanation. Adaptive navigation support (ANS) comprises all the ways to alter visible links to support hyperspace navigation (P. Brusilovsky et al., 1997). The idea of adaptive navigation support techniques is to help users to find their paths in hyperspace by adapting the way of presenting links to goals, knowledge, and other characteristics of an individual user. Currently several kinds of adaptive navigation support techniques are being investigated. *Direct guidance* techniques may suggest where the user should proceed according to the student's learning goals and state of knowledge (R. Zeiliger, 1993). *Adaptive annotation* applies visual cues to show the educational status of nodes behind the links, for example using different icons to show what is learned and ready to be learned (P. Brusilovsky et al., 1996a; B. de La Passardiere & A. Dufresne, 1992). *Adaptive hiding* reduces the cognitive load of the student by hiding less relevant links (T. Pérez et al., 1995). *Adaptive sorting* orders non-contextual links on hypermedia pages placing links that are most relevant for the given user in the given context to the top (H. Hohl et al., 1996; C. Kaplan et al., 1993).

Adaptive navigation support is currently a popular research area. A number of various techniques were suggested and developed (P. Brusilovsky, 1996). Unfortunately there is a big gap between development and evaluation of ANS techniques. The only evaluated ANS technique is an adaptive sorting technique implemented in HYPERFLEX system (C. Kaplan et al., 1993). This paper attempts to bridge this gap. It is centered on the study of adaptive navigation support in educational hypermedia. The object of the study is our system ISIS-Tutor, one of the first educational hypermedia systems with ANS. We present the results of our recent experiment that was aimed to test the effect of adaptive navigation support in educational hypermedia and to compare two techniques of support -- adaptive annotation and adaptive hiding of links. As far as we know, these two most promising techniques of adaptive navigation support have never been evaluated in a classroom study before.

2 The ISIS-Tutor system

ISIS-Tutor is an intelligent learning environment to support learning a print formatting language of an information retrieval system CDS/ISIS/M (ISIS for short). This system was distributed by UNESCO and used widely in Russia and in many information centers worldwide. The print formatting language is a kind of programming language with over 50 different commands and modifiers. It is used to display or print the result of a search, or the content of a database. A complete description of ISIS-Tutor can be found in (P. Brusilovsky & L. Pesin, 1994a; P. Brusilovsky & L. Pesin, 1994b).This section presents only those features of ISIS-Tutor that are required to discuss adaptive navigation support.

ISIS-Tutor is a combination of a hypermedia-based electronic textbook, an intelligent tutor, and an exploratory environment. The *hypertext component* of ISIS-Tutor supports student-driven learning in a hyperspace of educational material and provides adaptive navigation support. The nodes in the hyperspace are *units of learning material* (ULM). There are three kinds of ULM in ISIS-Tutor: concept presentations, problems to solve and examples (program fragments) to analyze. Each unit constitutes an elementary step of the learning process. Using the hypermedia interface the student can navigate in the hyperspace of learning material and select the next ULM to work. The *tutor component* supports guided tutoring (curriculum sequencing). If a student hesitates to select next ULM, the tutor component analyzes the state of the student knowledge reflected in the student model and selects the next most relevant ULM. Another duty of the tutoring component is to update the student model when current ULM is completed. More details about sequencing and student modeling techniques implemented in ISIS-Tutor can be found in (P. Brusilovsky & L. Pesin, 1994b). The *learning environment* allows the user to experiment with print formatting commands. It provides an editor and stepwise interpreter with extended visualization. Working with an example the student can use the exploratory environment which includes the visualizing interpreter. The environment lets him or her to play with the given example using the interpreter, to change the input data and the example itself. Working with a problem the student also can use the environment to design and test the solution.

The key to intelligent behavior of ISIS-Tutor is knowledge about the subject and about the student represented in a form of *domain model* and *student model*. The domain model represents the material being taught (knowledge about the print formatting language) as conceptual network. The material is divided into elementary *concepts* and structured as a directed graph (concept map) where the links represent several kinds of relationships between the elements including prerequisite relationship. The domain model in ISIS-Tutor contains 64 concepts.

The student model includes a model of student knowledge and a sequence of individual learning goals. A model of student knowledge represents the current level of student knowledge on the subject as "weighted overlay." It means that for each concept of the domain model the student model stores an integer value reflecting the extent to which the student has mastered this concept. The model of student knowledge is kept up-to-date by the tutor component and supports the adaptive capacity of all modules. The sequence of learning goals is assigned individually by a human teacher. Each learning goal is a set of domain concepts that has to be mastered before moving to the next goal. ISIS-Tutor provides a mechanism of learning goals as a way for a human tutor to adjust the system to his or her preferred order of presenting the material.

All ULMs are indexed with domain model concepts. ULMs are stored in the knowledge base of learning material as frames. Each of the ULM frames has a slot which contains the list of domain concepts related with this ULM; for example, the list of concepts required to solve the problem. This list (called the spectrum of the ULM) provides a link between the ULM and the domain model.

ISIS-Tutor uses a specific approach to implement educational hypermedia based on the following three ideas. First, the central part of the hypermedia network is designed in a form of visualized domain network. Each node of the domain network is represented by a node of the hyperspace, and links between domain network nodes constitute main bi-directional paths between hyperspace nodes. Thus the structure of the overall hyperspace resembles the pedagogic structure of the domain knowledge. Second, each ULM is also represented as a node of the hyperspace and connected to all domain concepts listed in its spectrum. Third, hypermedia 'pages' which are external representations of all the mentioned hyperspace nodes are not stored in a fixed format, but generated by the hypermedia component from their internal frame-based representation.

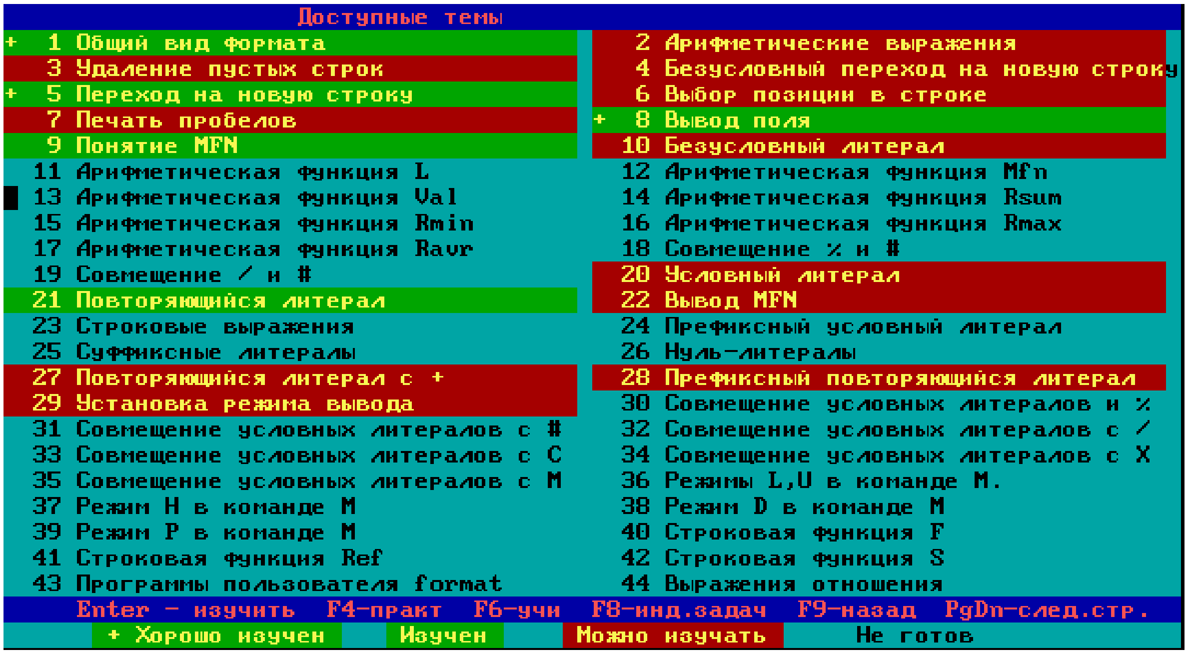

Figure 1. Concept index page of ISIS-Tutor with annotated links.

Scrolling is required to see the links to the concepts from 45 to 64.

Links to learned concepts are shown green. Links to ready to be learned concepts are shown red.

Links to not ready to be learned concepts are not annotated by color.

The hyperspace of educational material in ISIS-Tutor is naturally structured and tightly interlinked. The nodes of this hyperspace are concept presentations, examples and problems. Each node has many links to other nodes of all three kinds. These multiple links provide many ways of navigation. For example, the user can select a domain concept from the concept index (Figure 1), then move to a related construct, then to some example of its application. Here the user can use the environment to play with the example, then move back to the construct and repeat it with another example. Then the user can select one of the problems related with the construct to master the obtained knowledge. If the problem appears to be hard, the student can analyze the list of concepts in the problem spectrum and move from a problem to the concept that is not well understood (and which can be far away in the network from the starting concept). A user in ISIS-Tutor has many ways of navigation and many paths going from the current node to related nodes. To help the user to navigate in this tightly interlinked hyperspace the hypermedia component applies several adaptive navigation support techniques.

3 Adaptive navigation support in ISIS-Tutor

3.1 Direct Guidance

The most traditional technique of adaptive navigation support in ISIS-Tutor is a direct guidance technique. Direct guidance is implemented in ISIS-Tutor in a form of a special button "Teach me" which is available on any page presenting a concept or a problem, as well as on the index page and within the exploratory environment. This button activates an intelligent sequencing module of the tutor component. The sequencing module applies an embedded tutoring strategy to select the next ULM -- the most useful ULM according to the current state of user knowledge. To make a choice the sequencing module uses the domain and student models and the spectra of ULM. The selected ULM is presented to the student. The sequencing technique used in ISIS-Tutor is a simplified version of our general intelligent sequencing technique described in (P. L. Brusilovsky, 1992).

3.2 Adaptive annotation

In ISIS-Tutor, annotations of links inform the user about educational and goal status of related nodes. The hypermedia component uses the student model to determine current educational status for each concept represented by a hypermedia page: not-ready-to-be-learned (i.e., has unlearned prerequisites), ready-to-be-learned, known (learning started), and learned (student has demonstrated knowledge about the concept by solving the required number of problems for the concept). Our idea is that concepts with different educational status have different meanings for students and making educational status visible would help them in hyperspace navigation. To make educational status visible, the hypermedia component marks all links to concepts (local links as well as links from index) using colors and some special characters. The key point is that links to nodes with different educational status are marked differently. In the current version of ISIS-Tutor links to not-ready-to-be-learned concepts were not colored, ready-to-be-learned were colored red, both known and learned were colored green, and learned concepts were additionally marked with sign "+" (we used special signs to avoid using too many colors). Figure 1 shows the first part of the ISIS-Tutor concept index page with annotated links (scrolling is required to see the links to the concepts from 45 to 64).

Similar annotation technique is used to adapt link presentation to the current educational goal. As mentioned in the section 3.1, the educational goal in ISIS-Tutor is just a set of concepts that the student expects to learn at the current session. The difference between goal and non-goal nodes is also meaningful for the student. To make this difference visible the links to concepts that are within the goal of the current lesson are marked with a sign "-" while all other links have no goal-related mark. Thus, all the links to the concepts with different educational and goal status are marked differently using colors and special marks "+" and "-". The same way is used to annotate not only all links to concept pages, but also all links to problems and examples. As a result, all links in ISIS-Tutor are adaptively annotated by different colors and special marks. These annotations inform the student about the educational and goal states of all kinds of related pages (Table 1, column B).

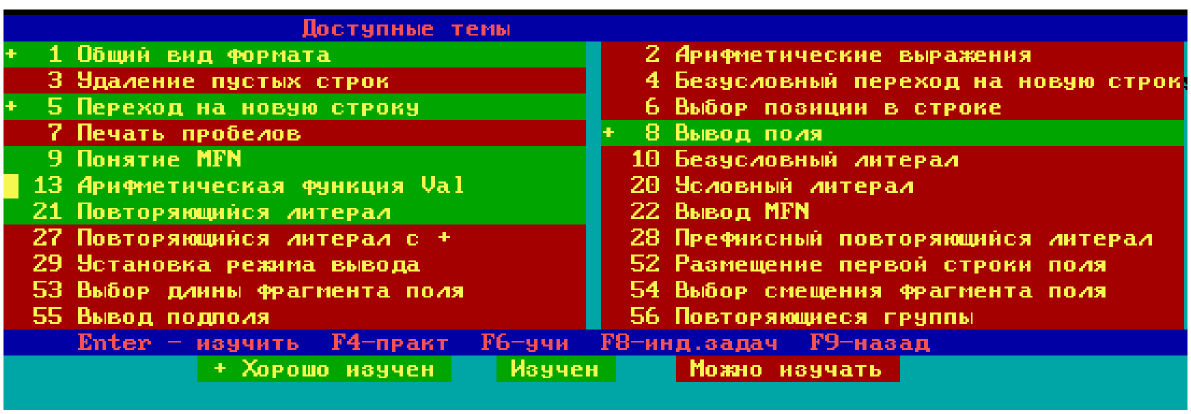

Figure 2. The same index page as on figure 1 with hidden links to not-ready-to-be-learned nodes

3.3 Adaptive Hiding

The idea of adaptive hiding in ISIS-Tutor is to reduce the cognitive load by hiding from the student all links to the nodes that the student is "not expected to learn." There are two kinds of these links in ISIS-Tutor: links to not-ready-to-be-learned nodes and links to the nodes that are outside the current educational goal. In "pure annotation" mode (i.e., when hiding is switched off) these links were not annotated (Table 1, column B). In "hiding" mode (i.e., when hiding is switched on) these links are hidden: they are removed from any menus and its position in the menus is occupied by the next visible links (Table 1, column C). As a result, all menus of links become much shorter for a novice who get most of the links hidden. For example, full index of concepts takes two screens in ISIS-Tutor (Figure 1). In the hiding mode the novice starts with the index containing just two links, and during first sessions the growing index still fits one page (Figure 2). Note that "hiding" mode in ISIS-Tutor is not a pure hiding but a combination of hiding and annotation. Learned, known and ready-to-be-learned nodes are still annotated differently as in normal annotation mode (Table 1, column C). In the most recent version of ISIS-Tutor hiding is an option which can be switched on and off. One of the reasons to implement hiding by this way was to test possible additional effect provided by hiding.

4 The Study

To test the effect of adaptive navigation support in educational hypermedia and to compare two most promising ANS techniques we conducted an experimental study. Special experimental version of ISIS-Tutor was used for the study. In addition to "annotation" and "hiding" modes the experimental version had a non-adaptive mode which works like a normal hypertext: nothing is hidden or annotated. Comprehensive tracing facilities were also provided. The direct goal of the study was to compare in the same educational context three versions of ISIS-Tutor: non-adaptive, adaptive annotation (we call it adaptive for short), and adaptive hiding (we call it restrictive for short because it restricts student choice). Non-adaptive version was set to non-adaptive mode, adaptive version was set to the mode with adaptive navigation support by annotation, and restrictive version was set to the mode with adaptive navigation support by annotation and hiding (Table 1). To avoid interference, direct guidance was switched off in all the three versions.

Educational status of the node behind the link	A. Non-adaptive	B. Adaptive annotation	C. Adaptive hiding
Outside educational goal	NA	NA	*hidden*
Within educational goal	NA	mark "-"	mark "-"
Well-learned	NA	mark "+"	mark "+"
Known	NA	green color	green color
Ready-to-be-learned	NA	red color	red color
Not-ready-to-be-learned	NA	NA	*hidden*

Table 1. Summary of annotations applied in three experimental versions of ISIS-Tutor. NA means no annotation.

Twenty-six subjects (11 males and 15 females) took part in the experiment. All subjects were 18-19 years old first year computer science students of the Moscow State University. At the moment of the study they had only two months of courses, so they can be considered as "computer science oriented", but not as "computer science professionals". All students have no previous experience of work with ISIS or ISIS-Tutor but have an experience of work with various computer systems. The subjects were divided randomly into three groups. "Non-adaptive" group (7 subjects) worked with non-adaptive version of ISIS-Tutor (as described above), "adaptive" group (8 subjects) worked with adaptive version and "restrictive" group (11 subjects) worked with restrictive version.

All subjects were briefly introduced to ISIS and ISIS-Tutor and were asked to complete the same part of the course on ISIS print formatting language. The part of the course selected for the experiment contains ten concepts (from 64 available), all related examples, and ten test problems which require not more than these ten concepts to be solved. The selected concepts were taken from the beginning part of the course and can be learned (according prerequisite relationships) without knowing any other concepts. These ten concepts and ten problems were set as educational goal to all students. Users of both adaptive groups could always see the goal concepts and tasks annotated by "-" mark. Users of non-adaptive group had a sheet of paper with the list of goal concepts and tasks. It should be noted that "the rest of the hyperspace" (i.e., the nodes outside the given set of concepts and tasks) was not forbidden for the students to visit. The students of non-adaptive and adaptive groups were free to investigate concepts, examples, and problems outside the educational goal. However, the students of "restrictive" group were not able to do that because any nodes outside the educational goal were hidden. The time was not limited. Each student completed the educational goal when all ten goal concepts were learned and all ten goal problems were solved.

All actions of the students working with the system were recorded as individual traces. These traces were then analyzed by a special program to compute several parameters which we consider as important for comparing the performance of the three groups. These parameters were used as dependent variables in processing the results of the experiment. The most important dependent variables were the time required to complete the course and the overall number of navigation steps. According to the results of the only similar experiment (C. Kaplan et al., 1993), we expected that both the time and the number of steps should decrease for adaptive versions. However we have no other definite hypotheses. So we computed 31 different dependent variables (half of them will be described later) to compare various aspects of user performance.

It appears that we failed to communicate to the students clearly enough that they are expected to achieve the educational goal as soon as possible and leave immediately after it. As we found later analyzing traces, some students treated the experiment more as a test and behaved as we expected, other students considered it also as a chance to play with an interesting system and sometimes keep working after all goal problems were solved. Some 5 students (one from non-adaptive, three from adaptive, and one from restrictive groups) misunderstood the goal to the extent that they have never visited some goal problems or goal concepts. Since the requirement to pass all ten concepts and problems was the key unifying requirement of the experiment, we had to exclude the data of these 5 students from consideration. All 21 considered subjects have really solved all 10 problems and visited all required concepts.

5 The Results

When processing the results, we have tried to find two kinds of effects. First, what is affected by adaptivity (i.e., what is different for non-adaptive group from one side and both adaptive and restrictive groups from another side)? Second, what is affected by a specific kind of adaptivity (i.e., what is different for adaptive and restrictive group)? We used three procedures to analyze the results of the study for each variable. First, we used ANOVA to check the difference between all the three groups. If there was no significant difference, we combined adaptive and restrictive groups into one joint adaptive group and applied non-paired t-test to compare this joined group with non-adaptive group. Also, when it was reasonable, we used non-paired t-test to compare adaptive and restrictive groups.

We have found only 11 dependent variables among 31 for which the difference between the groups was visible on a box plot. Moreover for most of these variables the difference appeared to be not significant, showing not more than a tendency. In the following subsections we show and discuss results for several groups dependent variables.

Group	Number of steps	Time (sec)	Concept repetitions	"Unforced" concept repetitions	Task repetitions
Non-adaptive	81.3	2196	17.3	11.2	6.2
Adaptive	65.2	1418	9.0	5.0	0.8
Restrictive	58.2	1785	8.9	4.8	0.4

Table 2. Mean values of performance parameters for three groups.

5.1 Global performance

The first group of dependent variables is global performance parameters which, as we expect, have to be affected by the navigation support. In addition to such parameters as overall time and overall number of steps, which have been considered in earlier experiments with navigation support (C. Kaplan et al., 1993), we were especially interested in finding patterns of inefficient browsing such as concept and task repetitions (Table 2).

Number of steps. ANOVA shows a significant difference between all the three groups (with ANOVA p-value 0.041) for the overall number of steps. A step here means a navigation step from one activity to another, for example, from one concept page to another concept page or from a concept to example. A visit to an example page or to the environment was counted as one activity even if the user managed to play with several examples in one visit. The number of steps for adaptive group is much smaller than for non-adaptive group and it is even slightly less for the restrictive group. The really significant difference was found between non-adaptive and joint adaptive group: unpaired t-test for non-adaptive versus joint adaptive group gives p-value 0.015. Thus, adaptive navigation support does provide navigation support, significantly reducing students' navigation efforts.

Time. The visible difference for overall time of work between non-adaptive and both adaptive group is not significant. In some sense, it means that the time decreased to a less extent then the number of steps. The most probable reason for that is the following. The overall time consists from time spent reading pages and navigation time spent on making navigation decisions and moving from page to page. Our hypothesis is that navigation support affects the navigation time but not the reading time. So, the effect of navigation support on the overall time should be less visible. Another similar hypothesis is that the users of adaptive groups spent more time working in example and practice modes. Each visit to the environment was counted as one step, though it usually takes considerably more time than a visit to a concept page. Unfortunately we have recorded only the overall time and can not check this hypothesis.

Concept repetitions. The number of concept repetitions, that is, repeated visits to the same concept page, is visibly less for adaptive groups. This difference becomes significant if we consider only "unforced" or "unexplainable" concept repetitions, i.e., exclude "natural" repetition of concepts after incorrect solution of a problem related to this concept (unpaired t-test for non-adaptive versus joint adaptive group gives p-value 0.048). A possible interpretation is based on the fact that in hypermedia some part of visits to related nodes are made not for learning, but for orientation. Students move to a related node for a short time just to check what is around. We think, that the number of short orientation visits is reduced with adaptive navigation support. Annotations may give the student enough information about related nodes to avoid visiting it in some cases. This hypothesis can also partly explain, why the time difference between adaptive and non-adaptive groups is not significant while the difference in the number of steps is significant. In any case adaptive navigation support reduces users' navigation efforts in hyperspace and makes the work more efficient.

Task repetitions. ANOVA shows significant difference (with p-value 0.007) for the number of task repetitions, i.e., the number of repeated trials to solve the same task. The number of repetitions is significantly less for adaptive groups (unpaired t-test for the non-adaptive versus the joint adaptive group gives p-value 0.0014). Our data shows that in many cases the students of the non-adaptive group entered the task page and leave it without a correct solution (and often without a single trial to solve the task). At the same time, students of adaptive groups almost always left a task page with a correct solution (mean value for the number of repeated trials is less than one for 10 solved problems!). It means that annotation-based adaptive navigation support, which recommends visiting ready-to-be-learned pages and warns against visiting not-ready-to-be-learned pages, works quite well.

5.2 Navigation

We have checked a number of parameters related with differences in navigation. For each kind of navigation (index->concept, concept->task, etc.) we have counted how many times it was used (Table 3). ANOVA shows no significant difference between groups for all navigation parameters (including concept->concept navigation where mean values for adaptive and non-adaptive groups look quite different). The users appeared to be very different individually in their navigation. In respect of kinds of navigation, many users seem to have preferred styles and the diversity of styles used within each group was quite big. In respect of visiting non-goal and not-ready pages, some users ("explorers") visited a number of them and some users never leave the "recommended" set of concepts and tasks. Since our groups were reasonably small, individual differences make any influence of adaptation insignificant. Yet, there is one interesting difference, which we consider important to report.

The use of index. The use of task index (i.e., the number of times the student uses task index page to navigate to one of task pages) visibly decreases from non-adaptive to adaptive version and from adaptive to restrictive. The difference between both ends in this row (i.e., between non-adaptive and restrictive group) reaches significance (t-test gives p-value 0.049). What is specific for index-based navigation? Our interpretation is that index is often used for navigation as an ultimate tool when the student has problems with finding a path in the hyperspace. Adaptive navigation support helps the student to find such a path (i.e., to navigate to a relevant task from a concept page) and decreases the need to use the index.

Group	Concept index	Concept -> concept	Concept -> task	Task index	Task -> concept
Non-adaptive	18.5	8.1	9.8	12.2	2.0
Adaptive	18.4	1.8	6.4	9.6	2.2
Restrictive	14.0	1.6	8.1	7.0	1.8

Table 3. Mean values of navigation parameters for three groups.

5.3 Recall

Originally, we expected that adaptation could improve navigation, but, since it will make the user navigation work easier, the user will have less clear understanding of the hyperspace structure. To check this hypothesis we have asked all subjects to complete a small recall test after they finished with the main part of the experiment. In the recall test the subjects had to reconstruct the structure of the learned part of hyperspace by simply drawing a network of concepts and links between them. We have counted how many correct concepts and links the students remembered, how many they not remembered, and how many wrong concepts and links they drawn (Table 4). We found no significant difference for any of these parameters.

Group	Recalled concepts correct	Recalled concepts incorrect	Recalled links correct	Recalled links incorrect
Non-adaptive	7.0	0.7	8.6	5.0
Adaptive	6.2	1.2	7.5	8.5
Restrictive	6.9	0.8	5.7	5.1

Table 4. Mean values of recall parameters for three groups.

All significant differences reported above were found between non-adaptive and joint adaptive groups. It means that we have demonstrated the value of adaptive annotation. At the same time, we have failed to determine any additional value of hiding in ISIS-Tutor context. No significant difference was found between adaptive and restrictive group for all collected parameters. One of the reasons may be the smaller number of subjects involved in comparison of adaptive versus restrictive group. Another possible reason is that annotation and hiding provide similar influence on user performance, so additional value of hiding is not visible when annotation is also used. To make a more careful comparison, we have to compare annotation with "pure" hiding.

Group	% users visited non-goal tasks	% users visited not-ready tasks	% users visited non-goal concepts	% users visited not-ready concepts	visited non-goal concepts
Non-adaptive	20	66	33	0	1.0
Adaptive	0	100	80	20	2.8
Restrictive	0	0	0	0	0.0

Table 5. Visiting "not useful" pages

The unique setting for restrictive group is hiding the "not useful" nodes: not-ready-to-be-learned nodes and nodes outside the current educational goal. It is interesting to check how often these "not useful" nodes were used in non-adaptive and adaptive versions (Table 5). What is important is the very number of visited "not useful" nodes and the fact that all but two students of both "non-restricted" groups visited at least one of such nodes. It gives us the confidence that freedom of navigation is important for the users and that annotation technique could be a better candidate for adaptive navigation support then hiding. The data also shows that the average number of visited "not useful" concepts and the number of users who visited it are bigger for the adaptive version. From one point of view, it is a really strange phenomenon: the users of adaptive group had annotation which warned them about not-ready and non-goal pages ... and they were more eager to visit it! From another point of view, we may say that the users who have navigation support feel themselves more confident in the "recommended" part of the hyperspace to allow some excursions outside this part. In any case, this difference is also not significant.

6 Discussion

Our experience with adaptive navigation support and the results of our experimental study show that adaptive navigation support is an efficient technology of hypermedia adaptation in an educational context. The method of adaptive navigation support in ISIS-Tutor is relatively simple, however it provides a significant effect. Main effect of adaptive navigation support by annotation and hiding in an educational context is reducing of the overall number of steps (number of visited nodes) required to learn a particular part of the course without reducing the quality of learning. The comprehension time is not affected significantly. These results are similar to the results of another experimental study of adaptive navigation support (sorting technique in an information retrieval context) reported in (C. Kaplan et al., 1993) and probably can be considered as a general effect of adaptive navigation support.

It is interesting to compare the effect of adaptive navigation support with the effect of adaptive presentation reported in (C. Boyle & A. O. Encarnacion, 1994). This work reports that adaptive presentation in hypermedia can reduce the time for learning the material and improve the comprehension of it, but cannot reduce navigation time and the number of nodes visited in the process of learning. At the same time, adaptive navigation support can hardly improve the quality of learning and the comprehension time, but it can reduce the number of visited nodes -- thus further reducing the overall learning time. These techniques look complementary and can be used together for further improvement of the effectiveness of adaptive hypermedia.

There is an evidence that the students working with adaptive navigation support (either annotation of hiding versions) feel themselves more confident and comfortable then the users of non-adaptive hypertext. In particular, they can afford time and cognitive efforts to learn something outside the educational goal, or to play more with the environment. A significant difference between annotation and hiding techniques of navigation support was not found; however there is an evidence that unrestricted freedom of navigation is important for the user. In this sense adaptive annotation technique can be preferred over adaptive hiding.

While claiming that annotation is a good technique for adaptive navigation support we do not claim that using colors is the best way of annotation. Colors can be less meaningful for the student than other ways of annotation. In addition, too many different colors on the screen are very distracting. We think that using icon-based (P. Brusilovsky et al., 1996a; B. de La Passardiere & A. Dufresne, 1992) or text-based (Z. Zhao et al., 1993) annotation is better in many ways. Unfortunately, it requires advanced display facilities, while ISIS-Tutor was limited to a DOS-based version of ISIS.

Adaptive navigation support is a very new area of research. More work is required to compare different techniques of adaptive navigation support and different variations of them in different contexts. However the results we have up to date are good enough to recommend adaptive navigation support (and in particular our method of adaptive navigation support) as an efficient technology to improve the functionality of hypermedia.

Ourselves, we continue our work with annotation-based adaptive navigation support in the context of Web-based educational hypermedia. The Web, which is a hypermedia system in its essence, is a very suitable area for applying adaptive navigation support techniques. We think that adaptation is especially important for Web-based hypermedia. First, most Web-based applications are to be used by a much wider variety of users than any standalone applications. A Web application, which is designed with a particular class of users in mind, may not suit other users. Second, in many cases the user is "alone" working with a Web application (probably from home). That is why an assistance that a colleague or a teacher typically provides adaptively in a normal classroom situation, is not available. The class of users who need adaptivity urgently are Web "newcomers" with almost no Web experience (and often no general computer experience). These users simply cannot cope with complex hyperspaces offered by modern Web-based applications. We think that the techniques of adaptive navigation support developed in ISIS-Tutor may be very useful in Web-based educational hypermedia. Currently, these techniques are implemented in two systems: ELM-ART (P. Brusilovsky et al., 1996a), an intelligent Web-based tutor for LISP and InterBook (P. Brusilovsky et al., 1996b), a tool for development adaptive hypermedia on the Web. Unfortunately we have not yet completed formal studies with these systems and cannot report how useful our techniques are in the Web context.

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Biography

Dr. Peter Brusilovsky received his M.S. degree (1983, Applied Mathematics) and Ph.D. degree (1987, Computer Science) from the Moscow State University. Before joining Carnegie Mellon he was a Humboldt Fellow at the University of Trier, Germany, and a Senior Research Scientist at the International Center for Scientific and Technical Information, Moscow, Russia.

Leonid Pesin received his M.S. degree in Applied Mathematics from the Moscow State University. Currently he works on his Ph.D. thesis and is employed as Webmaster of the Russian Trading System.

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Appendix I: Screenshot translations

Concept index

+	*1 General format*		**2 Arithmetic expression**
	3 Removing empty lines		**4 Unconditional go to new line**
+	*5 Go to new line*		**6 Selecting a position in a string**
	7 Printing blanks	+	*8 Field output*
	9 The concept of MFN		**10 Unconditional literal**
	11 Arithmetic function L		12 Arithmetic function Mfn
	13 Arithmetic function Val		14 Arithmetic function Rsum
	15 Arithmetic function Rmin		16 Arithmetic function Rmax
	17 Arithmetic function Ravr		18 Mixing % and #
	19 Mixing / and #		**20 Conditional literal**
	21 Repeating literal		**22 Printing MFN**
	23 String expressions		24 Prefix conditional literal
	25 Suffix literal		26 Null-literal
	27 Repeating literal with +		**28 Prefix repeating literal**
	29 Setting output mode		30 Mixing conditional literal and %
	31 Mixing conditional literal and #		32 Mixing conditional literal and /
	33 Mixing conditional literal and C		34 Mixing conditional literal and X
	35 Mixing conditional literal and M		36 L and U modes in M command
	37 H mode in M command		38 D mode in M command
	39 P mode in M command		40 String function F
	41 String function Ref		42 String function S
	43 User programs format		44 Relational expressions

Enter - learn F4-practice F6-teach-me F8-problem-index F9-back PgDn-next-page

+ *Well learned* *Learned* **Ready to be learned**

Figure 1a. Concept index page of ISIS-Tutor with annotated links (first half).
Scrolling is required to see the links to the concepts from 45 to 64.
This is a translation of the original Cyrillic page. Green color (learned) is shown in *italic* . Red color (ready to be learned) is shown in **bold**. Links to not ready to be learned concepts are not annotated.

Concept index

+	*1 General format*		**2 Arithmetic expression**
	3 Removing empty lines		**4 Unconditional go to new line**
+	*5 Go to new line*		**6 Selecting a position in a string**
	7 Printing blanks	+	*8 Field output*
	9 The concept of MFN		**10 Unconditional literal**
	13 Arithmetic function Val		**20 Conditional literal**
	21 Repeating literal		**22 Printing MFN**
	27 Repeating literal with +		**28 Prefix repeating literal**
	29 Setting output mode		**52 Positioning first line of the field**
	53 Selecting subfield length		**54 Selecting field fragment shift**
	55 Printing subfield		**56 Repeating groups**

Enter - learn F4-practice F6-teach-me F8-problem-index F9-back PgDn-next-page

+ *Well learned* *Learned* **Ready to be learned**

Figure 2a. The same index page with hidden links to not-ready-to-be-learned nodes.
This is a translation of the original Cyrillic page. Green color (learned) is shown in *italic* . Red color (ready to be learned) is shown in **bold**.