Interaction of domain expertise and interface design in adaptive educational hypermedia

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Abstract: In this paper, three experimental studies about adaptive educational hypermedia are presented. In all experiments, interaction effects of the post-hoc variable "previous knowledge of learners" and the adaptive treatments could be shown. The interaction effects have an impact on learners' score in knowledge tests, the time needed to browse adaptive hypertexts, their overall number of page requests, and the type of information requested by learners. While learners with higher previous knowledge seem to prefer non-restricting adaptive methods, learner with low previous knowledge can profit from the guidance of more restrictive adaptive methods.

Keywords: Adaptive educational hypermedia, navigation recommendations, student modeling, previous student knowledge, interface design

1 Introduction

Empirical evaluations of learning with hypertext have yielded contradictory results. On the one hand, adaptive annotations in educational hypermedia were shown to increase the effectiveness of learning and the learning speed (Eklund & Brusilovsky, 1998; Specht, 1998a; Weber & Specht, 1997). On the other hand, most results revealed a strong impact of learners' previous knowledge on the effects of adaptive annotation. Therefore, the following analysis tries to clarify the interactional effects between previous knowledge of learners and different variants of adaptive annotation in educational hypertexts. The data for the analysis was obtained in two laboratory experiments and one field study with the learning environment AST.

2 Experiment 1

In the first experiment, four groups of students had to work with different versions of a tutorial hypertext in the area of prionic diseases (a group of infectious diseases). In treatment *Text* (see Fig. 1) they were administered a regular non-adaptive hypertext. Treatment *Anno* (see Fig. 2) used red and green bullets for marking those links that were (not) recommended to students based on the system's current learner model. In treatment *Inc* (see Fig. 3), disrecommended links were removed, but were incrementally added as soon as the student had learned the necessary prerequisites. In treatment *IncAnno*, the adaptive methods of *Inc* and *Anno* were combined.

In der Geschichte der <u>Infektionskrankheiten</u> werden seit etwa 200 Jahren <u>Prionenkrankheiten</u> beim <u>Mensch</u> und beim <u>Tier</u> beschrieben. Ihr <u>Erreger</u> wie auch der <u>Obertragungsweg</u> konnten aber lange Zeit nicht identifiziert werden, trotz umfassender Kenntnisse über Symptomatik, zeitlichen Ablauf und Epidemiologie.

Figure 1: The main page of the hypertext in the experimental treatment Text

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Figure 2: The main page of the hypertext in the experimental treatment Anno

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Figure 4: The main page of the hypertext in the experimental treatment *IncAnno*

At the beginning of the experiment, all subjects had to answer a demographic questionnaire and a knowledge test (pre-test). The pre-test included 12 questions about central concepts of a curriculum in the area of prionic diseases with varying difficulty. Then, a short introduction to using hypertext and information about the specific experimental treatment was given. Subjects were then asked to carefully study all material that was available in the hypertext system, because they would be quizzed at the end of experiment. After the subjects had visited all hypernodes, the system automatically presented the final questionnaire (post-test). The post-test included all questions from the pre-test and additional questions about the usability and helpfulness of the adaptive methods. The time to read all hypernodes and the number of correctly answered questions were measured as the main dependent variables.

85 subjects completed the experiment. In the demographic questionnaire there were no differences in the experience with computers and the WWW experience between the four groups. In all experimental conditions there was a significant improvement of correctly answered questions from the pre-test to the post-test (t(84)=18,41; p 0,01). In the pre-test, the treatment group *Text* had the best results, while in the post-test the group *IncAnno* showed the best results. For browsing the hypertext, the group *IncAnno* needed less time than all other groups. Subjects in the condition *Text* needed more time than all others. The means of the two knowledge tests and the time to browse the hypertext for all four treatments are shown in Table 1.

Table 1: The means of the four groups for the knowledge tests and the time to browse the hypertext (significant figures are in bold).

	Treatment				
	Anno	Inc	IncAnno	Text	
Questionnaire before Learning	4,67	5,22	4,88	5,53	
Questionnaire after Learning	$10,0^{1}$	10,31	11,33	9,94	
Mean time of browsing (in sec.)	692	765	618	893	

To ascertain that the experimental groups did not differ in their previous knowledge about the domain, a variance analysis was computed on the data of the pre-test, which showed no significant differences $(F(3,81)=0,37\;;p\;0,05)$. A variance analysis comparing the treatments for the post-test showed no significant main effect for the adaptive annotation of hyperlinks $(F(1,81)=3,91\;;p=0,052)$ and no significant effect for the incremental linking $(F(1,81)=2,410\;;p\;0,05)$. Significant effects for both adaptive annotation $(F(1,81)=13,17\;;p\;0,05)$ and incremental linking $(F(1,81)=4,49\;;p\;0,05)$ could be shown for the time to browse the hypertext. Comparing the experimental group which had both adaptive methods (IncAnno) with the group that had no adaptivity (Text) showed a significant effect with respect to the number of correctly answered questions $(t(39)=2,38\;;p\;0,05)$ and the time needed to browse the hyperspace $(t(39)=-4,23\;;p\;0,05)$.

However, a post hoc split of learners into three groups (mean \pm 0 standard deviation) depending on the score in the pre-test revealed that a significant improvement in the knowledge test only holds true for students with *low previous knowledge* (F(2,82)=46,9; p 0,01). Learners with average or high previous knowledge did not learn significantly more in any of the adaptive treatments. They still profit from the shorter browsing time in the adaptive treatments, though.

We also found that in the adaptive treatments *IncAnno* and *Anno*, all learners worked faster through the whole hypertext than in the adaptive treatment *Inc*. (the difference between *IncAnno* and *Inc* was even significant (t(42)=2.6; p 0,05). One possible explanation is that in the *Inc* treatment, learners had to search for new hyperlinks that possibly appeared after learners had viewed their prerequiste pages. In the annotated treatments, in contrast, all potential hyperlinks were visible from the beginning. This interpretation is supported by the additional finding that the learners in the *Inc* group had a significantly

¹ These two figures were erronously interchanged in previous publications (Specht, 1998a; Specht, 1998b) which however had no impact on the overall results.

higher number of visits to already seen hypernodes than all other groups (F(3,81)=16,32; p 0,01). The result that the group *Inc* also visited already seen information nodes significantly more often than even the *Text* group allows the hypothesis that the inconsistency of the interface in the *Inc* treatment has a very negative impact on the overall navigational support. The addition of annotations amends the violation of the consistency principle of HCI caused by incrementally appearing hyperlinks, by virtue of the fact that they mark locations where hyperlinks may appear sometimes in the future (their adaptive colors are irrelevant in this function) We regard this finding as a confirmation of the old wisdom in HCI that adaptive methods can never be a remedy for bad interface design.

3 Experiment 2

The second experiment was a classical pre-post design where the students had to answer a knowledge test about a given curriculum at the beginning of the experiment and at the end of the curriculum. The post-test was automatically administered after students had seen all units of the curriculum. The experimental variation was that students either got a static introductory lesson (*All*) that contained the main prerequisites for the curriculum, got no introductory lesson (*No*), or that the system computed a special introductory lesson depending on the introductory knowledge test of the learners (*Filter*).

46 subjects took part in the experiment. No significant differences could be reported for the experimental treatments in the introductory knowledge test (for details see (Specht, 1998a). In the *All* treatment, learners showed a significant improvement from the pre-test to the post knowledge test (t(8)=-5.7; p 0,01). A post-hoc split of learners in two groups was then performed, where the split point was the mean of the pre-test results (this bifurcation rather than a tripartite split as in experiment 1 was chosen because of the smaller number of subjects). We found that it was mostly the students with low previous knowledge who got better in the *All* treatment (ceiling effects are unlikely). The mean scores are shown in table 2.

Table 2: The means of the two post-hoc groups for the knowledge tests.

	Low previous knowledge	High previous knowledge
Questionaire before Learning	7.79	12.28
Questionaire after Learning	12	12.9

Additionally students with low previous knowledge learned most in the *Filter* treatment, while students with high previous knowledge learned most in the *All* treatment. These results support the findings of experiment 1 in that there seems to be an interaction between previous knowledge and the effectiveness of different adaptive treatments in terms of knowledge gain.

4 Field study

In the field study, the courseware Adaptive Statistics Tutor (AST) was accessible to students of the University of Trier. Before working with AST, students had to fill out a demographic questionnaire and work on a pre-test about the statistics curriculum. The curriculum contained 23 concepts of descriptive statistics in 8 learning units (sections). With each section and concept, 5 to 15 tests were associated. When learners had mastered a certain amount of tests, the system assumed that the students had learned the respective concept. The students were allowed to work with AST as long and as much as they wanted, and the system was able to maintain the learner model over multiple sessions. Students where randomly assigned to three adaptive treatments:

- 1. Annotation of Hyperlinks (*Annotation*): A coloured bullet was presented with each hyperlink, which gave some information about the concept behind the hyperlink. The colour of the bullets was adapted to the knowledge state of the student. Green balls marked the corresponding link as a recommendation, orange balls were presented when all prerequisites to this concept had been learned, and red balls meant that the hyperlink leads to a hypernode whose prerequisites were not yet fully learned by the student.
- 2. Annotation of Hyperlinks and hiding of "red" hyperlinks (*Hide*): In this treatment, adaptive annotation of hyperlinks was realised as in treatment 1, except that those hyperlinks were hidden that lead to hypernodes that were "not ready to be learned. When a student had mastered all prerequisites of a concept, the hyperlink to this concept was made visible and presented with an orange ball. The annotation of hyperlinks with green balls was computed by the system taking into account the

knowledge state of a student, the learning material that had already been viewed by the student, and a didactic model for sequencing concepts and learning materials.

3. Annotation of learned and not-learned concepts (*Static*): In the third treatment, all annotations had the form of white balls and check marks, so learners only got information about what concepts they had already learned (check mark) and what concepts they still needed to work on (white ball).

In a period of three months, 180 subjects worked with AST. In the following study only 67 subjects are taken into account who had issued more than 20 requests to the system.

Table 3: The mean number of requests split by type of learning material and the experimental treatment

	Introduction	Text	Test	Summary
ANNOTATE	1.04	1.0	3.70	.64
HIDE	1.13	.59	5.39	.68
STATIC	1.01	.62	2.17	.40

One result of the study (see Table 3) was that the number of requests and the requested type of learning material were dependent on the adaptive treatment. Subjects in the *Annotation* group requested significantly more text material (F(1,2)=6.11; p 0.05) than the other groups, while the subjects in the *Hide* condition requested more tests (F(1,2)=5.77; p 0.05) than the other groups. The mean number of requests for the different learning materials are shown in table 3.

The number of requests was not confounded with the preferences for different materials specified in the introductory questionnaire. In the knowledge test before learning with AST, there were no differences between the experimental groups. A post-hoc split in three groups (mean \pm 1 standard deviation) depending on the results in the pre-test showed a significant interaction effect between the previous knowledge and the adaptive treatment on the number of information requests (F(4,71)=3.35;p 0.05). Students with the best results in a preliminary knowledge test worked more intensive with the system when they were in the *Annotate* group. Vice versa, students with medium results in the introductory test worked better (more requests) in the *Hide* group.

5 Discussion

In all three studies, interaction effects between the previous knowledge of learners and the adaptive treatments could be shown. First, learners with high previous knowledge seem to prefer working in less restrictive adaptive environments, and work more intense and have more profit if they have full access to all information. Nevertheless learners with high previous knowledge can profit from non-restrictive adaptive methods like the adaptive annotation of hyperlinks, however only as far as browsing time is concerned (see experiment 1 and field study).

Learners with low previous knowledge seem to profit from more guidance by adaptive methods and an adaptation of the available information to their current knowledge. The guidance of incremental linking must however be combined with indicators for the locations where links will appear, in order to save users from having to search for new links and request pages multiple times (experiment 1). When integrating adaptive methods in learning environments one should keep in mind that certain adaptive treatments can enforce certain learning strategies (see study 3 and request of certain learning materials).

The results and tendencies presented in these experiments should be validated in follow-up studies with experimental designs where previous knowledge is a controlled experimental variation.

6 References

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