Re-assessing the Value of Adaptive Navigation Support in E-Learning Context

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Abstract. In a recent study, we discovered a new effect of adaptive navigation support in the context of E-learning: the ability to motivate student to work more with non-mandatory educational content. The results presented in this paper extend the limits of our earlier findings. We describe the implementation of adaptive navigation support for the SQL domain, and report the results of the classroom evaluation of our approach. Among other issues, we investigate whether the use of two different types of navigation support in parallel could change the nature or the magnitude of the previously observed effect. Our study confirms the motivational value of navigation support in the new domain. We observe the increase of this effect after adding the concept-based navigation layer to the existing topic-based adaptive navigation service. The results of the navigational pattern analysis allow us to determine the major source of this increase.

1 Introduction

Adaptive navigation support emerged into a popular technology in modern e-learning. It is known to improve the learning outcome [1, 2], increase the speed of learning [3, 4], and encourage non-sequential navigation [5]. In our recent work we discovered another effect of adaptive navigation support: its ability to increase the amount of student work with non-mandatory educational content [6]. The magnitude of the observed effect was notably large – main usage parameters increased two to three times in the presence of navigation support. The effect also appeared to be stable: we were able to replicate it in three separate studies with two different systems – QuizGuide, which provided adaptive navigation support to a set of C programming quizzes, and NavEx, which offered adaptive navigation support for a repository of annotated C programming examples.

Our previous studies reported in [6] left several questions unaddressed. First, QuizGuide and NavEx implemented two different adaptation mechanisms. QuizGuide offered topic-based navigation support relying on a coarse-grained topic-level student model. NavEx implemented concept-based navigation support that employed more traditional and finer-grained concept-level model. While both types of navigation support caused statistically significant increase of user activity, we never applied them

at the same time. As a result, it was not clear whether we were observing the same effect caused by two slightly different technologies or we observe two complementary effects, which could potentially magnify the value of each other. Second, while we explored the motivational value of adaptive navigation support in two different systems, both systems were developed for the same domain (C programming) and both operated on a relatively simple content – quiz questions and examples, both requiring relatively low processing efforts from a student.

The work presented in this paper attempts to address both limitations of our earlier studies. We explored the value of adaptive navigation support in a different domain (SQL) and with more advanced educational content: SQL problems that require from a student to write fragments of SQL code as a solution. We also investigated whether the simultaneous use of both types of navigation support in parallel could change the nature or the magnitude of the previously observed effect.

The following two sections briefly describe the details of SQL problems offered to students, and the new implementation of QuizGuide adaptive hypermedia service. The evaluation part of the paper is divided between two sections: section 4 analyses the differences between adaptive and non-adaptive access to the SQL problems and reports the results agreeing to our previous findings [6]; section 5 compares two approaches of adaptive navigation support implemented in QuizGuide and investigates the added value of concept-based adaptation. Section 6 concludes the paper with final remarks and discussion.

2 SQL Knowledge Tester

SQL-KnoT (SQL Knowledge Tester) is a system performing generation, delivery, and assessment of online problems for testing and training knowledge of basic subset of SQL concepts. Every problem in SQL-KnoT asks a student to write a query for a set of sample databases resulting and a desired output. The system evaluates student answers on-the-fly and generates a feedback indicating whether the answer has been correct or not. For a number of recognized errors SQL-KnoT also provides students with corrective messages. An important feature of SQL-KnoT is the dynamic generation of typical problems based on the collection of pre-defined templates. As a result, when a student repeats a problem accessed before, the problem definition, the original databases and, consequently, the answer to the problem will be different. This allows students to master a certain skill through the sequence of typical exercises. Students can access SQL-KnoT problems with and without adaptive navigation support. Fig. 1 demonstrates the non-adaptive access to SQL-KnoT problems served by the KnowledgeTree learning portal. The left frame of the portal allows students to browse SQL-KnoT problems (and other types of learning activities) by lecture. The right (content) frame presents the selected problem to a student. Every SQL-KnoT template is associated with a topic and a set of concepts thus providing the basis for evaluation of the student knowledge and appropriate adaptation to it. The adaptive navigation for the problems is provided by QuizGuide service. Next section describes the implementation of adaptive access to SQL-KnoT problems and compares two versions of the QuizGuide interface employed for this study.

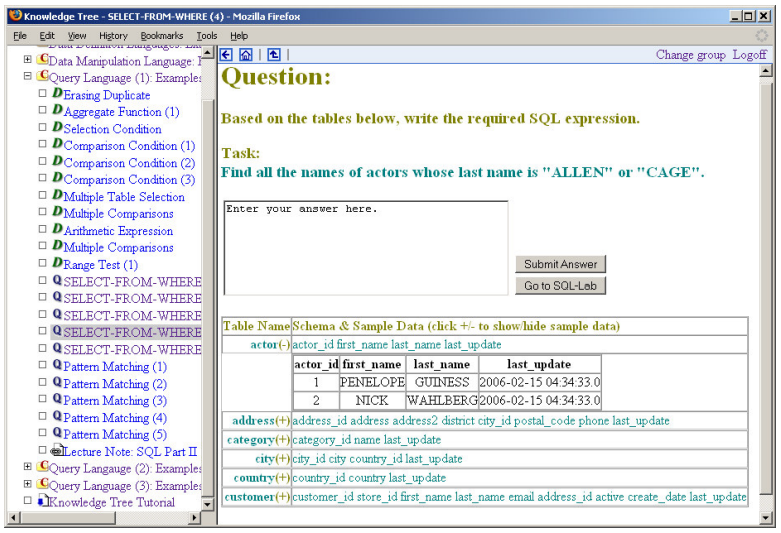

Fig. 1. Non-adaptive access to SQL-KnoT problems on the learning portal

3 Topic-based and Concept-based Adaptation in QuizGuide

QuizGuide is an adaptive hypermedia service providing students with individualized access to online educational content. It implements the principles of open learner modeling by presenting to a student the content of her/his user model in the form of navigational cues. QuizGuide groups learning resources into coarse-grained topics and annotates the topics with icons representing current student's progress for a corresponding topic. QuizGuide also adapts to the current learning goal of the student by highlighting relevant topics and shadowing irrelevant ones.

A distinct feature of QuizGuide as an adaptive educational system is its intensive employment in real classroom studies. Over the last four years the system has been used in more then 15 C/C++ programming courses in three educational institutions. During this period, more then 200 students have tried QuizGuide and access overall about 13 000 problems.

The new system prototype described in this paper implements two versions of adaptive navigation support for the same set of SQL-KnoT problems. Fig. 2a shows a sample problem accessed with the topic-based version of QuizGuide. The list of topics in the left frame is annotated with "target-arrow" icons, where the number of arrows reflects the current levels of knowledge for this topic (on a scale from 0 to 3). The color of the target indicates the relevance of a topic to the current learning goal of the class. As new topics are introduced in the class, the colors of topics change from the bright blue (current goal) to the grey (passed goal) or pale-blue (a prerequisite for the current goal). Topics that have not been studied yet are marked with crossed targets.

To explore the value of combined navigation support we have added a new layer of annotations to QuizGuide (see Fig. 2b). Every question icon represents the cumulative level of knowledge a student has demonstrated for the concepts underlying the

question. Concepts are much smaller knowledge elements then topics. A concept is usually related to multiple questions where it can play one of two roles: outcome or prerequisite. Outcomes are the concepts first introduced by the question, while prerequisites are the concepts that are present in the index of the question, but have been introduced earlier in the course. The order of questions (and prerequisite-outcome relations between their concepts) is defined by the order of course lectures and question-lecture associations. As in the topic-based version of the interface, questions answered correctly receive a checkmark; however, it is possible for a question icon to represent the maximum level of concept knowledge without being checkmarked. Such scenario is possible if a student has been practicing the material covered in the question by answering relevant questions sharing the same set of concepts.

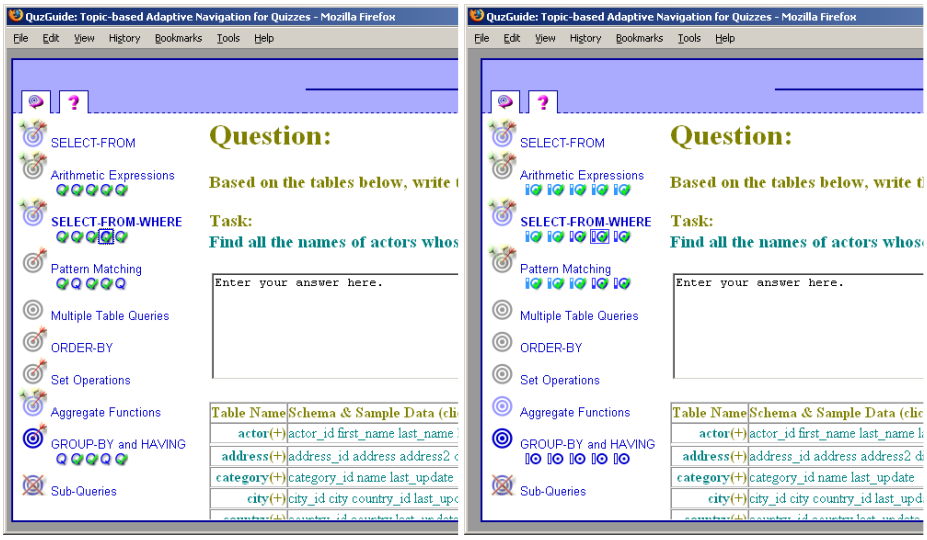

Fig. 2. Adaptive navigation for SQL-KnoT problems provided by QuizGuide:**a)** Topic-based; **b)** Topic-based combined with concept-based.

Fig. 3 summarizes all annotations used in both versions of QuizGuide interface. Large "target-arrow" icons (Fig. 3a) annotating topics are used in both versions; however, on the question level the interfaces differ. The only navigation support provided by the pure topic-based QuizGuide is a checkmark denoting a question solved correctly at least once (Fig. 3b). The interface combining topic-based and concept-based adaptation to annotate questions uses small targets with vertical progress bars (Fig. 3c). The progress of a student for the concepts underlying the question is double-coded: as the knowledge level grows, the icon fades and the bar level rises. By means of this abstraction, QuizGuide tries to deliver to a student two messages: where the progress has been made (higher bar level) and where the attention should be focused (brighter target color). To help a student understand the meaning of annotations, for all icons QuizGuide dynamically generates mouse-over hints. The detailed help explaining all interface elements is available as well.

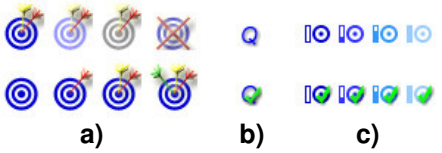

Fig. 3. QuizGuide annotations: **a)** Topic-based (upper row – levels of topic relevance to the current learning goal; lower row – knowledge levels for the topic); **b)** Question progress (done / not done); **c)** Concept-based (four knowledge levels combined with question progress).

One of the challenges in developing the new interface of QuizGuide was the implementation of immediate feedback. To update the navigation state reflecting recent activity the older version of the system needed a user to click the reload icon. Practical evaluation showed that this feature was often neglected by students. It was not critical for the topic-based navigation as the topic knowledge levels grow relatively slow. However, introduction of the concept-based annotation has demanded higher level of interactivity, as a single correct answer can change the annotations for several questions sharing the same outcome concepts. Therefore, for both versions of QuizGuide interface we have implemented an AJAX-based component updating all relevant icons after every student's answer. This update increases the transparency and predictability of the system interface; a student can immediately observe the results of the correct answer to a problem and make an appropriate decision for the next step.

4 Confirming the Value of Adaptive Navigation Support

We evaluated QuizGuide in two classroom studies in the Fall, 2007. The system was used as a learning tool in one graduate and one undergraduate database classes (38 and 36 students correspondingly) taught by the same instructor. Each version of the system provided access to 46 SQL-KnoT problem templates. Each template was accessible in both ways – through QuizGuide (adaptive mode) and though the learning portal (non-adaptive mode). Within QuizGuide, templates were grouped in 10 topics (Fig. 2). Within the course portal, they were placed in the corresponding lecture folder (Fig. 1). All user interactions with the systems were logged. For every problem-solving attempt, the associated log record contained template ID, time of the attempt, access point (QuizGuide or portal), and the attempt result (success of fail).

To investigate the value of adaptive navigation support, we looked at such usage parameters as the number of attempts, the number of distinct problems attempted, the number of sessions and the session length. The logs of 19 graduate students and 26 undergraduate students received at least one problem-solving record over the semester. Several students have been eliminated from the further consideration as outliers because of the very low or extraordinarily large numbers of attempts. Overall, students attempted 4074 problems in QuizGuide and 1230 problems in non-adaptive mode. Because the system was introduced to the graduate students much later in the course, the total number of attempts made by the undergraduate students was considerable larger. Nevertheless, the observed difference was stable for both courses – adaptive access to the problems dominated non-adaptive.

The results of the evaluation confirm our hypothesis. The students were much more willing to access problems in the adaptive mode (through QuizGuide), and the use of the adaptive mode caused them to work more. The magnitude of the effect was comparable with our earlier studies [6]. On average, students from both courses made more than twice as many attempts and tried more than twice as many problems in the adaptive mode. They also explored more topics on average; however, the statistical test does not show the significant difference for this parameter. We attribute this to the fact that the number of available topics was too small (only 10); therefore, for many active students a ceiling effect has been observed. Tables 1 and 2 show the results of statistical tests comparing major usage characteristics between adaptive and non-adaptive modes, separately for the undergraduate and the graduate courses. Because, the assumptions of parametric statistics were violated; Wilcoxon Signed Rank Tests has been applied.

Table 1. Comparison of Cumulative Usage Parameters for Adaptive and Non-adaptive Modes (Graduate Students)

	Adaptive	**Non-Adaptive**	**p-value**
Average Number of Attempts	52.47	19.29	0.022
Average Number of Problems	27.53	12.71	0.056
Average Number of Topics	6.29	3.53	0.093

Table 2. Comparison of Cumulative Usage Parameters for Adaptive and Non-adaptive Modes (Undergraduate Students)

	Adaptive	**Non-Adaptive**	**p-value**
Average Number of Attempts	69.48	34.92	0.073
Average Number of Problems	21.28	10.64	0.048
Average Number of Topics	5.20	3.76	0.243

The difference in the amount of work might be caused by more frequent access (greater number of sessions) and/or by longer sessions. Although the average number of adaptive sessions was higher, the difference between two groups was not significant. At the same time, the average length of an adaptive session (27.33 attempts) was significantly higher then the average length of a non-adaptive session (11.00 attempts) *Mann-Whitney* $U = 6359.5$, $p < .001$. This confirms our previous findings (see [6]), that in the presence of adaptive navigation support students stay with the system longer and do more work per session: i.e., the use of the system becomes "addictive".

5 The Added Value of Concept-based Adaptation

To investigate the difference between the two versions of QuizGuide interface and determine the added value of the concept-based navigation we divided student from both courses into two groups. Over the semester, the experimental group used the concept-based QuizGuide (Fig. 2b), while the control group had access to the topic-based version (Fig. 2a). The non-adaptive access to the same set of SQL-KnoT problems, as well as all other course tools was equally available for both groups. The groups were balanced with respect to the student gender and pre-test score. After

filtering out outliers, the experimental group contained 13 students (7 undergraduate and 6 graduate), and the control group – 15 students (8 undergraduate and 7 graduate).

5.1 Evaluation of Student Motivation and Persistence

The analysis of main usage parameters, that could indicate further increase in user motivation with the introduction of an additional layer of navigation support (such as the number of attempts, the number of sessions, and the session length), did not show stable significant results[1]. However, the comparison of the average number of attempts per question for both courses shows a statistically significant difference. The assumptions of parametric statistics have been violated; therefore, we have used the non-parametric Mann-Whitney test. The results of the test indicate that students using the concept-based interface on average made significantly more attempts per question (*M=3.36, SD=2.66*) then those using the topic-based interface (*M=1.68, SD=0.42*), *Mann-Whitney U statistics=51.0, p=0.033*.

Such increase in question persistence led to another statistically significant effect. The comparison of student knowledge levels taken from their user models at the end of the semester showed that the students from the concept-based group achieved higher resulting knowledge levels (*M=0.45, SD=0.09*) then the students from the topic-based group (*M=0.39, SD=0.03*), *t(26) = 2.71, p=0.023*.

The comparison of student activity over the semester has also shown that, on average, students from the experimental group used the system more consistently over the semester. Similar to what we observed in [6], students have been employing QuizGuide in two main learning scenarios: for routine self-assessment through the semester and as a preparation tool for the final exam. Consequently, we could identify two corresponding clusters of transactions, stable across all groups. The comparison of the ratios of transactions that belong to a particular cluster showed, that students from the concept-based groups worked more over the semester then those from the topic-based group (79.35% of all transactions comparing to 66.04%). The examination of these clusters demonstrated considerable differences in students' work with the system in terms of exploring system content, reacting to the its feedback, and following its navigational cues.

The next section analyses in details the low-level navigational patterns followed by the students in QuizGuide and reports an important difference in the distribution of this patterns between the experimental and the control group.

5.2 Navigational Pattern Analysis

To obtain a deeper understanding of how students of two groups work with QuizGuide and respond to the adaptive guidance it provides, we performed detailed evaluation of student sessions in QuizGuide. As a result, we could identify seven basic patterns of navigation characterizing the transition of a student from one problem to another (Fig. 4 represents these patterns in a graphical form):

[1] While for undergraduate course concept-based group significantly dominated topic-based group on these parameters, the effects did not hold for the graduate course.

- *Sequence*: a student moves from topic to topic, and inside a topic from the first question to the last;
- *Repetition*: a student attempts the same question again immediately after the previous attempt;
- *Go-Back*: a student decides to return to one of the previous questions inside the same topic;
- *Skip-In*: a student skips one or several questions by moving to the next question within the same topic;
- *Skip-Out*: a student skips one or several questions left in the topic by moving to the first question of the next topic;
- *Jump-Forward*: a student moves to an arbitrary question of a topic lower in the list;
- *Jump-Backward*: a student moves to an arbitrary question of a topic upper in the list.

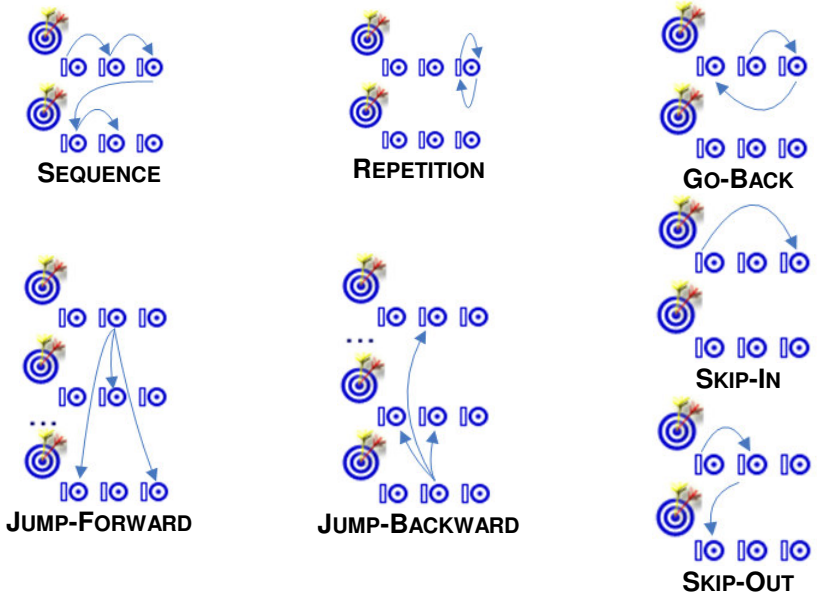

Fig. 4. Observed navigational patterns

Sequential patterns are typical for a session, when a student has a pre-defined plan to practice a set of topics and does not pay much attention to navigational cues. Unlike *Sequence*, all other patterns are not based on the pre-planned strategy neglecting system's feedback, but appear as a responce on either the navigation served by QuizGuide or the feedback generated by SQL-KnoT. For example, *Jump-Forward* and *Jump-Backward* patterns are guided mostly by the topic annotations, when a student decides to switch to a topic with a smaller number of arrows or to review a prerequisite of the current learning goal. *Skip-In* pattern can happen because the student does not like the question or because the concept-based navigation does not recommend focusing on the question guiding a student to another question within the same topic, etc. In general, there is more then one potential scenario for every pattern.

One of the traditional goals of adaptive navigation is to promote non-sequential patterns and guide a student in the most effective way to the novel content, for which the student is currently ready. However, the evaluation of QuizGuide patterns showed that most of them are dominated by the sequential problem access. The ratios of such patterns as *Go-Back*, *Skip-In*, *Skip-Out*, *Jump-Forward*, and *Jump-Backward* did not exceed 10% for any of the group. No significant effects of the concept-based adaptation on the presence of these patterns have been found either.

However, for the second most popular pattern – *Repetition* – the presence of the concept-based annotations had a dramatic effect. Generally, *Repetition* has two major sources depending on the result of the previous user's attempt:

- $Repetion_0$: when the previous answer is incorrect, a student is likely to retake the same question to remedy the error, check a different guess and, finally, get a checkmark for the question;
- $Repetion_1$: when the previous answer is correct, but the student still decides to retake the question.

While the $Repetion_0$ portion is stable across all the groups, introduction of concept-based annotations increases the overall ratio of $Repetion_1$ from 1.72% to 17.20% for undergraduate students and from 2.33% to 16.61% in the graduate course. That means the adaptive concept-based question icons make students to repeat the same question again and again even after the question has been solved correctly. The presence of a checkmark ensures that the students are aware about the question status, which singles out the only reason for such behavior – the students were trying to earn a greater level icon for the question. This observation explains two significant effects reported in the previous section:

- the average numbers of attempts per question is greater for the concept-based group, because students repeat the same question more often in the presence of adaptive navigation support on the question level;
- the resulting knowledge levels are greater for the concept-based group, because student give more correct attempts to the same questions in order to receive an icon of the higher level corresponding to the higher level of knowledge;

This result also confirms the motivational value of adaptive annotation on the concept-based level. The students once again become "addicted" to the adaptive icons – they continue drilling in the same question in order to achieve the maximum possible level of annotation.

The observed effect has both positive and negative outcomes. From one point of view, students follow the adaptive navigational cues, become involved and motivated by the system, which make them work more and in a meaningful way. However, on the other hand, repeating the same question multiple times after the question has been solved correctly is not the desired usage pattern. The goal of the concept-based navigation in QuizGuide is to help students shift focus from the questions that have received some progress to those that have not been answered correctly yet. Drilling in the same material to obtain the maximum possible level of annotation and neglecting the rest of the questions is not the optimal learning strategy.

6 Discussion

This paper reports two major experimental results:

- we could confirm our previous finding of the motivational effect of adaptive navigation support in a new domain with a new type of interactive content;
- we observed a further increase of this effect as the concept-based navigation support was added to the existing topic-based interface of QuizGuide system.

The detailed analysis of student sessions determines that the main pattern underlying the added-value of the concept-based adaptive navigation is a generally undesirable drilling pattern. There are several possible remedies for this problem:

- reducing the adaptive navigation support to the topic-based level (in this case the students will not become too "addicted" to the question links and will be choosing the appropriate question within a topic independently);
- a more accurate concept-based adaptation granting students with maximum levels of annotations without unnecessary repetitions (this will require much finer adjustment of the modeling formula as well additional analysis of conceptual models of the question);
- combination of the pure glass box approach [7] implemented currently in QuizGuide with the direct guidance (this would allow to break undesirable patterns when a better navigational option is available).

We plan to further investigate this issue and compare several possible strategies. The final goal of this study is the interface design for an E-Learning hypermedia service inheriting the addictive nature of adaptive navigation support and maximally promoting the non-sequential navigation within the limits of in-class usage.

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