QuizMap: Open Social Student Modeling and Adaptive Navigation Support with TreeMaps

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Abstract. In this paper, we present a novel approach to integrate social adaptive navigation support for self-assessment questions with an open student model using QuizMap, a TreeMap-based interface. By exposing student model in contrast to student peers and the whole class, QuizMap attempted to provided social guidance and increase student performance. The paper explains the nature of the QuizMap approach and its implementation in the context of self-assessment questions for Java programming. It also presents the design of a semester-long classroom study that we ran to evaluate QuizMap and report the evaluation results.

Keywords: TreeMap, Open Student Model, Open User Model, Information Visualization, Self-Assessment, Social Guidance

1 Introduction

Open student modeling and adaptive navigation support are among the most popular technologies in modern personalized E-Learning. Open student models (also referred to as open learner models) allow students to observe their progress and reflect on their successes and failures [1-2]. Open models are especially beneficial when presented in visual form, providing students with an easy-to-grasp and holistic view on their learning [3-5]. Adaptive navigation support [6] guides students to the most appropriate education content. This technology is known for its ability help students acquire knowledge faster [7], improve learning outcomes [8-10] and reduce navigational overhead [7].

In our recent work on topic-based adaptive navigation support [11-12], we attempted to combine the benefits of open student models and adaptive navigation support. We structured educational hyperspace into topics and annotated topic links with adaptive icons showing both the progress of student knowledge of the topic and relevance of each topic to the current learning goal. In this way, a set of link annotations offered a visualization of student topic-level progress, while each of these links provided an immediate access to learning content for this topic. As our studies in three different domains demonstrated [11, 13], the combined approach allowed to significantly increase the quality of student learning and student motivation to work with non-mandatory learning content. Yet, we believed that the combined approach has not reached its full potential since, by the nature of topic-based navigation support, it was provided on the topic level, i.e. the system was able to recommend the whole topic as most appropriate to a specific student at given time, but was not able to distinguish individual questions within this topic as more or less relevant.

This paper reports our attempt to explore a richer integration of open student modeling and adaptive navigation support. The key idea of our new approach was to enhance the original topic-based navigation support with social navigation [14]. Social navigation guides users to relevant information by showing the traces of past users' work. In our past work, we demonstrated that social navigation in education context could successfully guide students to relevant content down to the level of an individual item [15]. Main challenge in adopting classic social navigation approach to our target content, a set of parameterized self-assessment questions for Java, is that the work of past users with questions can be reflected by two parameters (instead of usual one): the number of attempts to solve a specific question (a parameterized question can be attempted several times!) and the success rate (the fraction of correct answers) for the question. We believed that both kinds of information could be important to guide future users to most appropriate questions. To address this challenge, we explored the use of TreeMaps for student progress visualization. TreeMap is an expressive tile-based visualization approach that allows to present two parameters at the same time using the size and the color of individual tiles, while easily integrating the progress of many individual users in a single map.

The focus of the paper is *QuizMap*, a TreeMap-based visual interface for accessing self-assessment questions in Java, which provides using a combination of open social student modeling and social navigation support. In addition to the unique integration of social navigation, open student modeling, and navigation support, QuizMap extends the benefits of visualizing the student models from the cognitive aspects to the social aspects. By exposing student model in contrast to his/her peers, QuizMap is expected to provide social guidance and increase student performance. Following a brief review of similar work, we introduce the target domain and explain how a QuizMap for this domain is organized. Next we explain the design of a semester-long classroom study that we ran to evaluate QuizMap and report the evaluation results. Finally, we summarize this work and discuss future research plans.

2 A Summary of Related Work

2.1 Open Student Models

A range of benefits have been reported on opening the student models to the learners, such as increasing the learner's awareness of the developing knowledge, difficulties and the learning process, students' engagement, motivation, and knowledge reflection [3-5]. Dimitrova et al. [16] explored interactive open learner modeling by engaging learners to negotiate with the system during the diagnosis process. Chen et al. [17] investigated the active open learner models in order to motivate learners to improve their academic performance. Both individual and group open learner models were studied and demonstrated the increase of reflection and helpful interactions among teammates. In [6], Bull & Kay described a framework to apply open user models in adaptive learning environment and provided many in-depth examples.

2.2 Social Visualization in E-learning

While visualization as an approach becomes more and more popular in E-Learning context, we can find only a handful of work that explores the value of social visualization, i.e., presenting students some information about the whole class or their peers. Vassileva and Sun [18] investigated the community visualization in the online communities. They summarized that social visualization allows peer-recognition and provides students the opportunity to build trust in others and in the group. Bull & Britland [19] used OLMlets to research the problem of facilitating group collaboration and competition. The results showed that optionally releasing the models to their peers increases the discussion among the students and encourages them to start working sooner. CourseVis [20] is another example, yet one of the few open user model systems that provide graphical visualization for multiple users of groups to teachers and learners. It helps instructors to identify problems early and prevent some of the problems with distance learning.

2.3 TreeMaps

A TreeMap is a space-filling visualization method for representing hierarchical information [22]. By dividing the display area into a nested sequence of rectangles whose areas are associated to attributes of the data set, it effectively illustrates the structural information with slices and dices. TreeMaps have been applied to a wide variety of domains ranging from financial analysis [23], petroleum engineering [24] to network security analysis [25]. Some studies have focused on specialized techniques to visualize large number items on a TreeMap without aggregation [26]. The innovative idea to use TreeMaps to visualize a model of individual learner knowledge was first suggested in [27].

3 QuizMap – A TreeMap-Based Open Social Student Model

QuizMap is a TreeMap representing a work of a user group (such as a class) with self-assessment questions. We customized the TreeMap by using the size and color of the rectangles to display the performance of the student. To adapt the TreeMap approach to the context of self-assessment questions, we structured system's TreeMap into 4 levels. Each level of the TreeMap clusters different level of information in detail. The top level consists of 1 root node, which represents the summary information of the entire class, including the overall attempts, successful rate and average statistics. The second level consists of 21 nodes corresponding to topics covered within the class. Under each topic node, next level is formed by the parameterized self-assessment questions belonged to the topic. The bottom level of the TreeMap shows performance of each individual student in a group for each question. The QuizMap structure is presented in Figure 1.

The sizes of the rectangle for each node represent the amount of work done. The color indicates the amount of knowledge gained (credited with each successful answer). The student own performance is colored in orange and to contrast with the rest of the class, colored in blue. The darker the color, the higher success it presents and vice versa. Both reddish yellow and bluish color tints can be decomposed into 10 different “shades” (Figure 2). All the absolute values of the performance are displayed when user hover over the rectangle. These two different color schemes are meant to make it easier for the student to compare his or her performance with the performance of individual peers and the whole class.

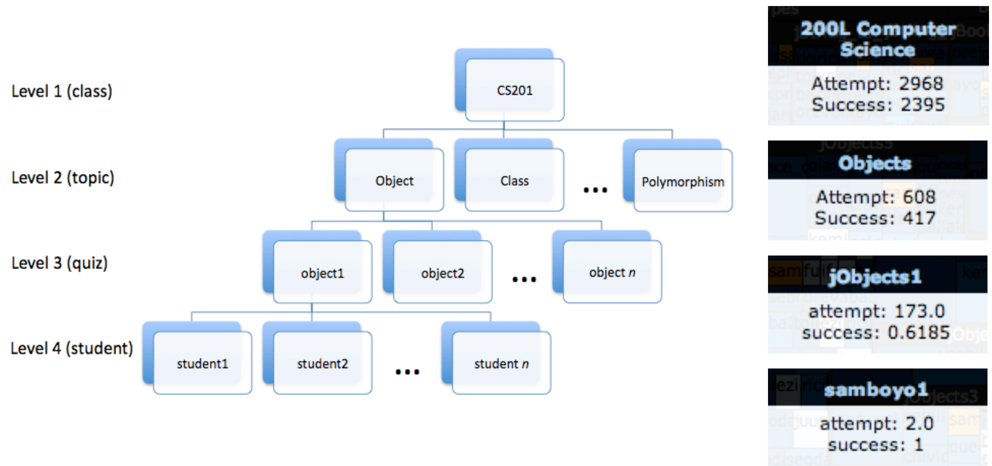


Fig. 1. QuizMap structure.

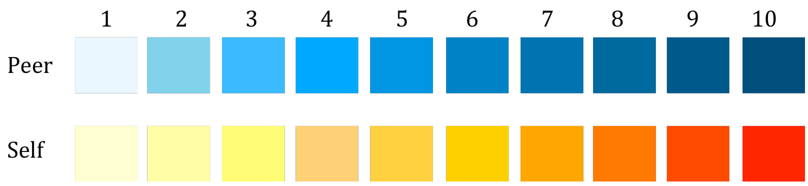


Fig. 2. QuizMap rectangle color shades indication.

To illustrate the use of the TreeMap in the context of self-assessment quizzes, Figure 3 represents an overview of QuizMap. To answer a quiz, a student has to select the question from each topic in the QuizMap. Upon the selection, QuizMap will pop a separate window to display the question (Figure 4). Each question asks the student to predict the results of execution of a specific Java program (i.e., mentally execute the program and enter the final value of some variable of the text to be printed by the program.) All questions are parameterized, i.e., include a random parameter, which the system instantiates when the question is delivered to a student. As a result, the student can attempt to answer the same question multiple times with different values of the parameter, which helps to achieve the mastery level. The implementation and functionalities of parameterized self-assessment quizzes were described in detail in [10].

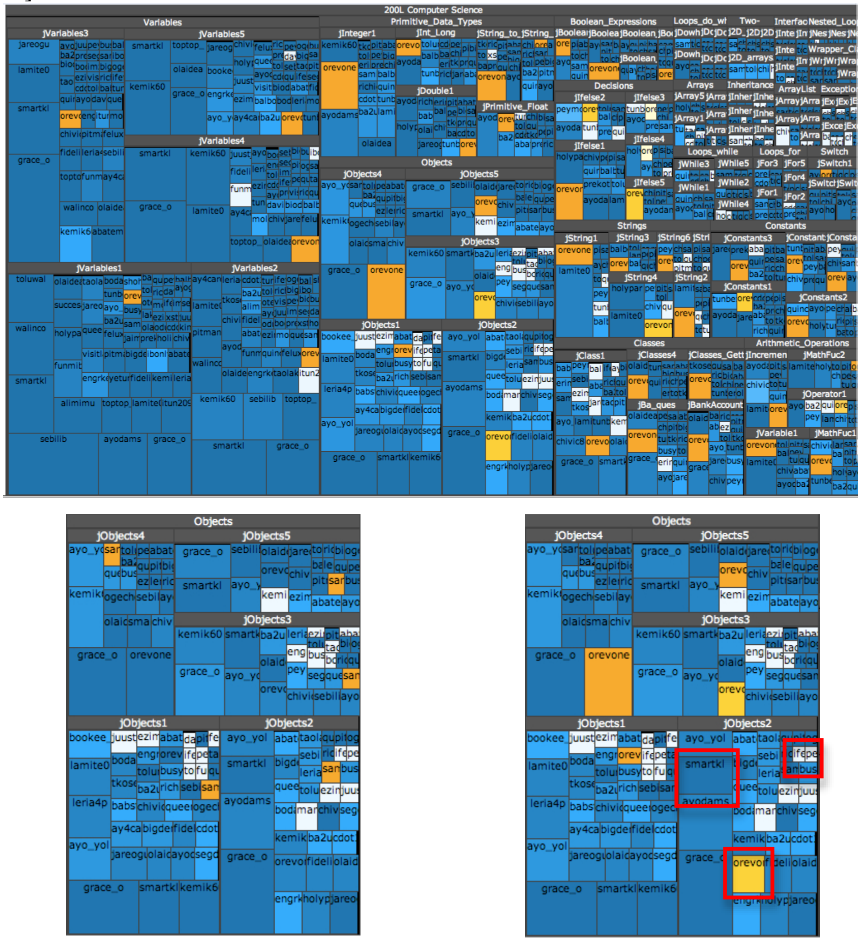
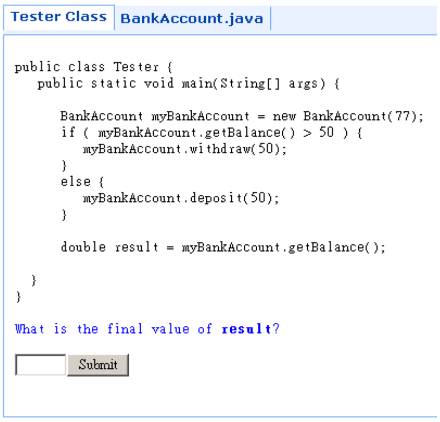


Fig. 3. An overview of QuizMap (top); A zoom in view on topic *Objects* of two students, student A (bottom-left) & student B (bottom-right)

The bottom part of Figure 3 shows two zoom-in views of the same topic, Objects, for two students. It demonstrated the amount of work done by the student A (Figure 3 bottom left) were relatively the same amount of questions on this topic. The color indicates a roughly 70% successful rate across all questions that s/he attempted. It suggested that this student had been consistent on performing different levels complexity of questions. Such way of evaluation can also be found throughout the class on his/her model. However, the other zoom-in view of QuizMap by student B (Figure 3 bottom right) displayed a different scenario. The student focused on working on certain questions, especially the *jObject4* question, which reached relatively high attempts. Throughout the class, he also followed the similar pattern of work. He had more attempts on a particular set of questions repeatedly and achieved the 50~70% successful rate. It suggested that this student might have troubles in those topics. Therefore, he kept trying again and again on the same questions to improve himself. In this open social student model TreeMap, students are expected to identify the strengths and weaknesses of themselves and their peers. For example, in the example of lower QuizMap, the student was struggling (low successful rate) with the question *jObject2* under the topic *Objects*. QuizMap provides the opportunities for him to discover stronger peers by recognizing dark blue rectangles. Vice versa. This student should also realize that who have less success on this specific question by recognizing the lighter blue rectangles. Those students may have lower chances to help him achieve a better understanding in this question.



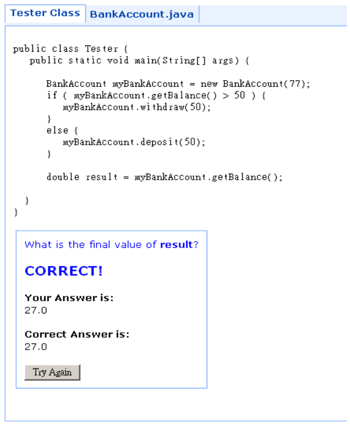


Fig. 4. A parameterized self-assessment question (left); a correctly answered question with evaluation results (right)

4 Classroom Study and Evaluation Results

We conducted a classroom study in the Programming and Algorithms course offered by University of Ibadan. The students were second year Computer Science majors. There are 86 students in the class – 52 male and 34 female. Out of them, 77 students were taking the course first time while 9 were repeating the course. The essence of the course is to build on the foundation they already have and teach Algorithm concept using Java and C++, thus enabling them build complete working program from the algorithm. Lectures were conducted through face-to-face interaction with the students. Assignments were submitted online by email attachment. Students already had introductory knowledge of Java in the first semester. Therefore, the QuizMap was introduced to the class as a supplemental tool. Students were encouraged to use QuizMap after being acknowledged that QuizMap quizzes will appear in the exam up to 10% of the marks. A major problem encountered by the students during the semester was the internet access issue. Access to internet in the school lab was only available for very limited hours which did not fit properly into the students' schedule most of the time. Sometimes, electricity was also a problem. As such, students could not use the computers in the laboratories at those times.

4.1 System Usage and Learning Gain

We analyzed the log data on students' interaction with the social visualization on the self-assessment quizzes (QuizMap) and compared the usage with the data from a comparable Object-Oriented Programming class at the University if Pittsburgh where students accessed the self-assessment quizzes using a traditional course portal with no visualization (QuizJET). Table 1 shows the basic statistics on both systems. There were 65 students who used the QuizMap. They made 2961 attempts to the questions, on average 45.55 questions per student. Students achieved 79.30% on average successful rate on answering the self-assessment questions. On average, students tried 4.55 distinct topics, 17.07 distinct questions and had 4.29 visits on the QuizMap. Comparing to QuizJET, the students who worked with QuizMap made less attempts and explored fewer topics (it could be related to the computer and internet access problems). Despite that, they achieved almost a much higher success rate. This level of success rate is typical for question access mediated by adaptive navigation support [11-13]. This provides some evidence that social navigation support is comparable to classic adaptive navigation support by its effectiveness. To obtain more reliable evidence a study should be repeated with more comparable groups.

Table 1. Summary of the overall usage on QuizJET and QuizMap

		QuizJET	QuizMap
All	**Users**	16	65
	Total Attempts	1293	2961
Average	**Attempts per user**	80.81 ± 22.06	45.55 ± 6.67
	Success rate	42.63% ± 1.99%	79.30% ± 1.94%
	Distinct Topics	7.81 ± 1.64	4.55 ± 0.59
	Distinct Questions	33.37 ± 6.50	17.07 ± 2.78
	Sessions	3.75 ± 0.53	4.29 ± 0.54
	Pre-test Scores	9.56 ± 1.29	7.55 ± 0.49
	Post-test Scores	17.12 ± 0.86	13.25 ± 0.60

To examine the connection between the amount of student work with QuizMap and their learning, we categorized students into three groups: passive, mild, and active users. Passive users are defined as ones who made less than 10 attempts; Mild users are ones who use the system moderately (10~45 attempts); Active users are defined as those who use the above the average (45 and more attempts, see the mean in Table 1). Table 2 summarizes usage data for each group. We found that active users explored 10.13 distinct topics and 38.13 distinct questions on average. It is not surprising that the numbers were significantly higher than the usage of passive users. However, they were also significantly higher than the data of mild users. The results demonstrate a connection between student learning and system use. The more they worked on the system, the more likely they discovered more topics. In addition, we found that the more active the students were, the higher learning gain they achieved.

Table 2. Detail QuizMap usage by student activity (only consider the users who took both pre- and post- tests)

Parameters	Passive (n=13)	Mild (n=22)	Active (n=14)	*p*
Attempts	8.36	40.68	76.13	<.01
Success Rate	93.1%	73.9%	77.41%	
Distinct Topics	1.00	2.82	10.13	<.01
Distinct Questions	2.35	10.36	38.133	<.01
Average Sessions	1.71	2.77	7.00	
Learning Gain	3.71	3.77	6.4	<.05
Pre-test score	6.64	7.32	8.73	
Post –test score	10.36	11.09	15.13	

4.2 Effects on Social Guidance

What is the mechanism of social guidance? How this approach based on the "collective wisdom" of a student community can guide students to the right questions as successfully as classic knowledge-based guidance? In our past work, we found evidence that in social guidance systems stronger students with better understanding of the subject lead the way discovering most relevant resources and creating guidance trails for weaker students. In order to investigate the social guidance effect in QuizMap, we categorized students into two groups, strong and weak, based on their pre-test scores (ranging from a minimum of 0 to a maximum of 20). Strong students scored 10 or higher points in the pre-test, and weak students scored less than 10 points. In Figure 5, we plotted all attempts over the course period. X-axis denoted as course period; Y-axis denoted as the topic complexities sorted from easy to complex. Blue data points represent strong students and orange points are the weak ones. We found that both strong and weak students started simultaneously on the easy topics. However, over time stronger students tended to run ahead of weaker ones. Weaker students approached new topics after the stronger ones had already explored it. Such behavior is more noticeable for more complex topics. The pattern indicated that stronger students, indeed, guided the weaker ones to the proper questions. This allowed weaker students to achieve success rate and post-test scores that are close to those of stronger students. At the end of the course, they narrowed the knowledge gap and achieved higher learning gain that stronger ones (Table 3).

Table 3. QuizMap usage by strong/weak student

Parameters	Weak (n=29)	Strong (n=22)
Attempts	33.17 ± 6.89	54.18 ± 13.40
Success Rate	77.91% ± 3.30%	83.29% ± 2.70%
Distinct Topics	3.93 ± 0.83	5.18 ± 1.06
Distinct Questions	13.37 ± 3.64	20.23 ± 4.99
Average Sessions	3.52 ± 0.51	4.00 ± 0.67

Learning Gain (post-pre)	7.55 ± 0.89	3.22 ± 1.12
Pre score	4.86 ± 0.53	11.1 ± 0.35
Post score	12.41 ± 0.96	14.32 ± 0.98

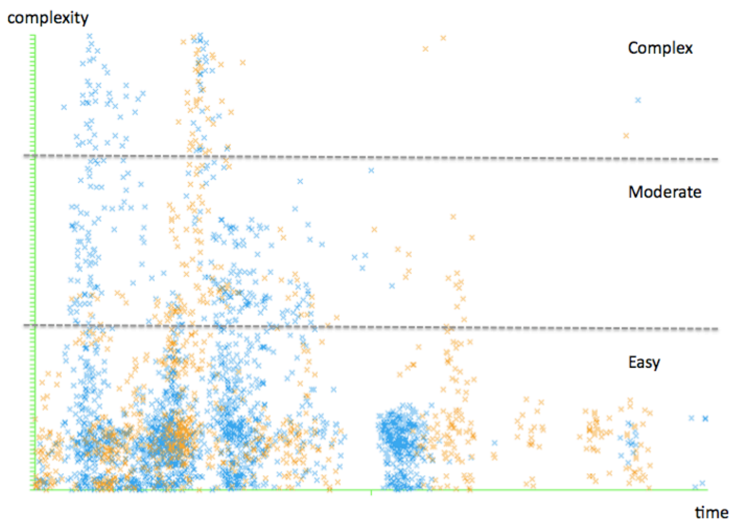


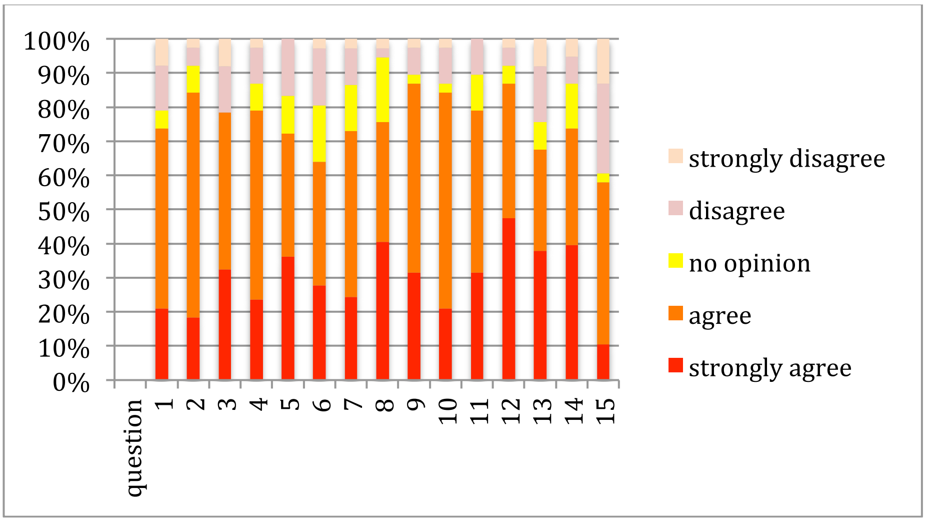
Fig. 5. Strong students guided weak students to explore the topics overtime. Blue data point represents strong students' attempt; orange data points represents the weak ones.

4.3 Subjective Evaluation

At the end of the semester, the students were asked to evaluate the system by filling out a questionnaire. We received a lot of praise and criticism. 78.8% of the students considered the QuizMap visualization motivated them to solve more quizzes. We can further hypothesize that the color contrasts on the QuizMap helps to motivate student to solve more quizzes while the rest of the student peers have already progressed on such. About 72~78% of the students strongly agreed or agreed that the QuizMap helped them to explore more topics and questions. We expected an even higher percentage of satisfaction on exploring the quizzes and questions. However, due to the size of the large size of the class and students' active work on the system, QuizMap generated 1105 cells in total. Some students complained that there were too many cells making it easy to lose focus. Over 80% of the students strongly agreed or agreed that they benefited from the self-assessment quizzes as well as the QuizMap visualization. Figure 6 displays the detail percentage for each survey question.

6 Summary

This paper described a novel approach to integrate social navigation for self-assessment questions with open user model in a TreeMap interface. The hierarchical representation of TreeMap was implemented to help students visualize both, the state of their knowledge and the progress of the whole class. Color contrasts between personal progress and the progress of others students were used to provide social guidance. The classroom demonstrated that QuizMap visualization provided effective social guidance allowing students to achieve high quality of learning. The effect was comparable with the impact of traditional knowledge-based guidance. The potential key to the success of the social guidance is the trailblazing behavior of stronger students who explored the topics and left the trace for weaker students to follow. In general, student satisfaction with QuizMap was high. However, there is also an evidence that the QuizMap approach may not be optimal for larger classes that generate too many cells on the TreeMap, causing it to become too crowded.



1. Online self-assessment quizzes helped to understand difficult concepts.
2. Online self-assessment quizzes helped to prepare for exams.
3. Online self-assessment quizzes contributed to my learning in this course.
4. The QuizMap visualization motivated me to solve more quizzes.
5. The QuizMap visualization helped to explore more topics (quizzes).
6. The QuizMap visualization helped to explore more questions.
7. The QuizMap visualization helped me to choose appropriate quizzes.
8. The QuizMap visualization showed the group's performance(blue color grids) and mine(orange ones) are clear.
9. I benefited from the self-assessment quizzes.
10. I also benefited from the QuizMap visualization.
11. Online self-assessment quizzes helped to discover my weak points.
12. Online self-assessment quizzes brought back forgotten concepts to my memory.
13. I am motivated to continue using online self-assessment quizzes after completing this course.
14. I think I will also benefit from self-assessment quizzes and QuizMap visualization in other courses.
15. The online self-assessment quizzes and QuizMap provided for easy navigation and I have minimal problems using them.

Fig. 6. Subjective Evaluation: Questions and Results

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