Liu, C.-C. et al. (Eds.) (2014). Proceedings of the 22nd International Conference on Computers in Education. Japan: Asia-Pacific Society for Computers in Education

Exploring Student Interactions with Tutorial Dialogues in a Substep-based Tutor

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Abstract: Understanding students' interactions with Intelligent Tutoring Systems (ITSs) allows us to improve the system as well as our pedagogical practices. Engaging students in tutorial dialogues is one of the strategies used by ITSs, which has been proven to improve learning significantly. This paper presents preliminary findings of a project that investigates how students interact with the tutorial dialogues in EER-Tutor using interaction videos in addition to eye-gaze data. We discuss some frequent misconceptions and behaviors student exhibited. Students usually focus on correcting one error at a time and then immediately submit their solutions to get feedback, thus not taking advantage of opportunities to reflect on what they have learnt. Based on the results, we identify several future directions of work on using eye-tracking for on-line adaptation.

Keywords: Substep-based Tutor, Tutorial Dialogues, Eye Tracking

1. Introduction

Studies of human one-on-one tutoring suggest that the student's behavior is a stronger predictor of learning gain than the tutor's behavior (Chi et al., 2001). Therefore, it would be beneficial to understand how students interact with ITSs. However, most evaluation studies involving ITSs focus on their effectiveness and do not explore student behavior deeper. In recent years, researchers have started analyzing student behaviors such as "gaming the system", or investigating how students attend to feedback (Baker et al., 2009; Conati, Jaques and Muir, 2013; Kim, Aleven & Dey, 2014).

We are interested in students' behavior while they solve problems in conceptual database modeling. EER-Tutor (Zakharov, Mitrovic & Ohlsson, 2005) is an ITS that teaches conceptual database design. We have enhanced EER-Tutor with tutorial dialogues (Weerasinghe, Mitrovic & Martin, 2009), which engage the student in discussing a mistake made. Tutorial dialogues help students learn relevant domain concepts as well as reflect on their errors. Many studies have shown the benefits of tutorial dialogues, such as (Evans & Michael, 2006; Graesser, 2011; Weerasinghe, Mitrovic & Martin, 2010).

Because we are mainly interested in the effect of dialogues on student behavior, we focus on students' actions following tutorial dialogues. For example, do students follow advice given in dialogues about how to correct errors? Verbal protocol analysis has been the dominant technique to analyze human tutoring. In this work, we analyzed student-system interaction videos and eye-tracking data. We describe our study and the version of EER-Tutor used in the following section. Section 3 presents the findings, while the final section presents our conclusions and future work.

2. Study

The interface of EER-Tutor (Figure 1) shows the problem statement at the top, the toolbox containing the components of the EER model, the drawing area on the left, and the feedback area on the right. Students' diagrams are checked for constraint violations on submission. The model for supporting tutorial dialogues is out of the scope of the current paper, and we refer the interested reader to (Weerasinghe, Mitrovic & Martin, 2009) for details. When a student makes one or more mistakes, s/he is presented with a tutorial dialogue. The problem statement, toolbar and drawing area are disabled but visible for the duration of the dialogue, and the error is highlighted in red in the diagram. In the situation illustrated in Figure 1, the student has incorrectly modeled *facility* as a regular entity type, and EER-Tutor has highlighted it and provided a tutorial dialogue related to that error.

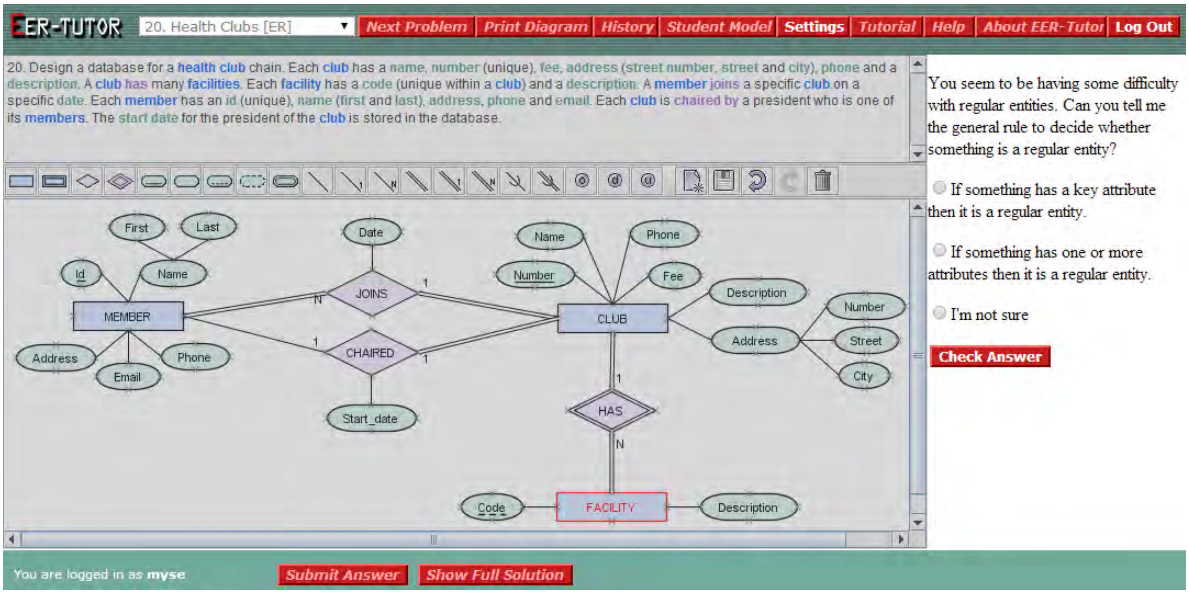

Figure 1. EER-Tutor interface after submission – the tutorial dialogue appears on the right

A dialogue consists of a sequence of questions, each with several possible answers. Such structure of tutorial dialogues allows multiple aspects of a single error to be discussed. The student answers by selecting an option, or asks for additional help (by selecting the "I'm not sure" option). Dialogues consist of the following prompt types:

- Conceptual (CO): discusses the relevant domain concept independently of the problem context. This is shown in Figure 1: the student has modeled *facility* as a regular instead of a weak entity type, so the conceptual prompt shown is asking about the basics of regular entities.
- Reflective (RE): aims to help students understand why their action is incorrect in the context of the current problem. For example, if the student answers the prompt in Figure 1 incorrectly, the RE prompt requires the student to specify why *facility* is not a regular entity type.
- Corrective action (CA): gives the student an opportunity to understand how to correct the error. For the error in Figure 1, the CA prompt is asking the student to specify the best way to model the *facility* and giving different options. Not all dialogues have this prompt type.
- Conceptual reinforcement (CR): allows the student to review the domain concept learnt. For the error in Figure 1, the CR prompt asks the student to identify the difference between a weak entity and a regular entity from the given options. Again, this is a problem-independent prompt.

The participants were 27 students enrolled in a database course at the University of Canterbury (9 females), aged from 18 to 50 years old (mean = 23.8, sd = 7.3). All participants had normal or corrected-to-normal vision. During the week prior to our study, the participants had used EER-Tutor in a regular lab session. Each participant was given a NZ$20 voucher and took part in the study individually. One student was excluded because no eye-tracking data was collected

We used a version of EER-Tutor modified slightly to make eye tracking easier. A calibration phase with the eye tracker (Tobii TX300) was carried out at the beginning of the session. The participants could work on three problems and were free to move between problems. They were instructed to attempt all problems and to submit their solutions regularly. Each student was given 50 minutes to solve the problems. The mean session length was 49 minutes (sd = 3.1 min).

We have previously analyzed the difference in behavior between novices and advanced students on all three problems in (Elmadani, Mitrovic and Weerasinghe, 2013). In this paper, we focus on the first problem only (shown in Figure 1), and analyze the actions the students take immediately after tutorial dialogues. The mean time spent on the first problem is 16.1 minutes (sd = 8.7 min), with students making an average of 6.2 submissions (sd = 5.3). 17 students successfully completed the problem, three of whom had solved it previously and re-did it for the study.

We focused on the video segments beginning when the student submits his/her answer for the final dialogue prompt and ending when the student next submits their solution to the same problem, the session ends or the student switches to another problem. There were 111 such segments.

3. Findings

The completeness of the solutions at the point the students first asked for feedback varied. Nine participants submitted complete solutions as their first attempt (only one was error free). One student submitted a solution excluding connectors, participations, and cardinalities. This student may have wanted to check that s/he has the correct entities, relationships, and attributes before thinking about the associations between them. Relationship attributes were left out from otherwise complete solutions by four students, highlighting the concept's complexity.

We investigated the errors made when answering the final dialogue prompt, which represent common or deep misconceptions. These errors were made by more than one student, or made several times by the same student. There is a lack of understanding of the differences between regular and weak entity types, and related concepts. For example, each weak entity type must have exactly one identifying relationship type. Two participants mixed up which relationship type belonged with which entity type. Students also show misunderstanding about which key type belongs to which entity type.

The cardinality ratio of relationships is a similarly difficult concept. There were nine situations where students indicated that in order to determine the cardinality ratio of a relationship, you must ask how many instances of an entity participate with another entity. This is incorrect as you must think in terms of a single instance of the second entity. One student made this error four times (two of which were in consecutive dialogues but pertaining to separate errors), which suggests that the student was not applying the tutorial dialogue content beyond correcting the current error.

Participation is a concept related to the cardinality ratio, so students may confuse the two. Five students thought that when determining the participation of entities in a relationship type it was necessary to consider how many instances of an entity participate with a single instance of another entity. On the contrary, it is necessary to consider whether every instance of an entity participates in relationship instances. One student answered this prompt incorrectly twice despite being able to correct the participation the first time s/he saw the prompt. This indicates that s/he may be relying on the fact that there are two participation options and so just chose the other one to correct the error.

Once the student receives the final message of a dialogue, s/he can go back to editing the diagram. Regardless of whether the student reads or looks at that final message, the red error highlighting is almost always the next focus of attention. This visual cue is therefore beneficial to students as they are able to quickly locate the error and concentrate on its correction. In addition, for cases where there is no error highlighting on the diagram, the students fixate on the toolbar or problem statement straight away. This is consistent with the type of errors made, for example submitting a solution with a missing entity type and therefore searching for it in the problem statement.

There were 20 students who answered the final prompt correctly and fixed the error (in 60.4% of all segments). After the tutorial dialogue, the student is free to change the diagram. We identified several common patterns of changes done:

- *attempts_fix*: the student addresses the error but incorrectly
- *fix*: the student corrects the error
- *check*: the student inspects his/her solution or rearranges diagram components
- *similar*: the student corrects a similar error
- *related*: the student makes related changes
- *other*: the student continues working on other parts of the solution
- *problem*: the student looks at the problem statement
- *wrong_issue*: the student tries to fix the error by addressing the wrong issue

A correction is attempted in 93.7% of segments, with 82.0% of these fixes being correct (made by 22 students). There were seven segments during which the student did not attempt to correct the error but switched to a different problem instead. One participant did not understand the tutorial dialogue. After completing the dialogue, s/he examined the text of the problem and all components of the diagram, and then attempted creating another entity type which was not necessary. The participant was clearly confused; s/he even looked at the other two problems before submitting the unchanged solution. This particular situation is illustrated in Figure 3 as a gaze plot generated by Tobii.

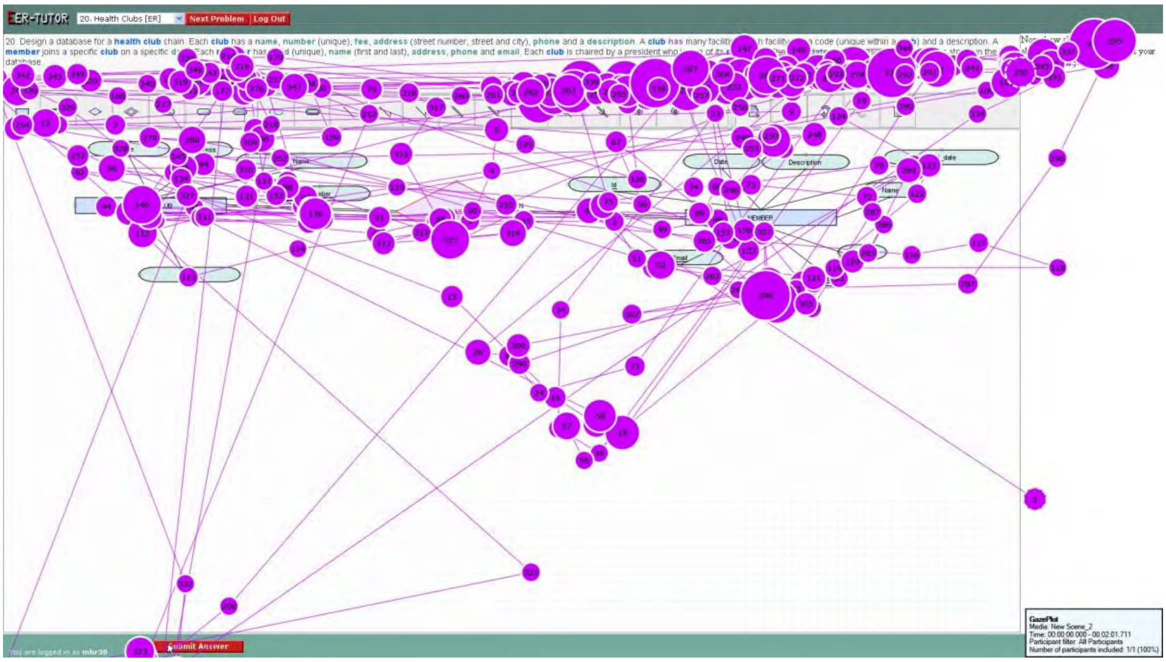

Figure 3. A gaze plot illustrating confusion

We also analyzed sequences of patterns following tutorial dialogues. There are 20 students who performed the *submit-fix-submit* sequence (row *a* in Table 1). That is, the student submitted his/her solution (*submit*), went through the tutorial dialogue, corrected the error (*fix*) and submitted the solution again (*submit*). A gaze plot illustrating this kind of situation is given in Figure 4. The student has submitted a solution with two mistakes, and received a dialogue about one of them. Upon completing the dialogue, the student quickly corrected their mistake, and submitted the modified solution for checking immediately. In this particular situation, there was another similar mistake in the solution, but the student has not taken the time to check the other parts of the solution.

Therefore, the dialogues may be encouraging shorter interaction sequences. Most participants addressed one error at a time and submitted their solutions to be checked immediately. With the exception of one student, students who solely followed this interaction pattern saw at most two multi-level dialogues (eight students in total). The next most frequent sequence (Table 1, row *d*) adds a single step, where the student checked his/her solution themselves before asking EER-Tutor for feedback. The other interaction patterns are shown in Table 1.

If the student has learnt from the dialogue, s/he should also be able to fix similar errors in the solution. This occurs in 7.2% of segments by six students (Table 1, rows *g*, *j*, *k*). These participants fixed the errors that are either the addition of missing constructs (relationship and cardinality) or correcting participation, cardinality or relationship type. Three of these students had also answered the final dialogue prompt correctly as well as fixing the error discussed in the dialogue (5.4% of segments).

If the student is reflecting on what s/he has learnt in a dialogue, s/he should be able to make related changes required. A related change is needed if the type of entity is changed for example, as the corresponding key and relationships would need modification. In 13.5% of segments, other related changes are required but these related changes are only made in 5.4% of segments (Table 1, rows *i* and *m*). Interestingly, there are no cases where a student fixed similar errors as well as made the required related changes. This is probably due to the relatively small number of components in this problem as there were limited opportunities to fix similar errors.

In 12.6% of segments, the student made further additions/deletions/changes to his/her solution prior to submission. These are situations in which the student continued to work on the problem or presumably decided to narrow the scope of his/her solution in order to focus on addressing the error discussed by the tutorial dialogue. 11 students demonstrated this behavior (Table 1, rows *e*, *h*, *i*, *k-m*).

There are cases where the student attempted to correct an error but did so by addressing the wrong issue (Table 1, rows *c* and *l*). One student, for example, had the wrong cardinality ratio but changed the participation instead. A similar situation occurred where a student had the wrong relationship type and, despite answering the corrective action prompt correctly, changed the cardinality on one side of that relationship. In that situation, the student got the same dialogue again because the system selects the most frequent error. The student then addressed the error by removing the cardinality s/he just added and changed the participation for another relationship. It is not until the next submission that the student corrected the error, suggesting s/he finally focused on and/or understood the dialogue content. Another student had a missing relationship attribute and, instead of adding it, changed the relationship type. The tutorial dialogue explicitly mentioned that this relationship was modeled correctly and fixations appeared on the feedback area when this text is displayed. This suggests that the student may not have fully comprehended the dialogue.

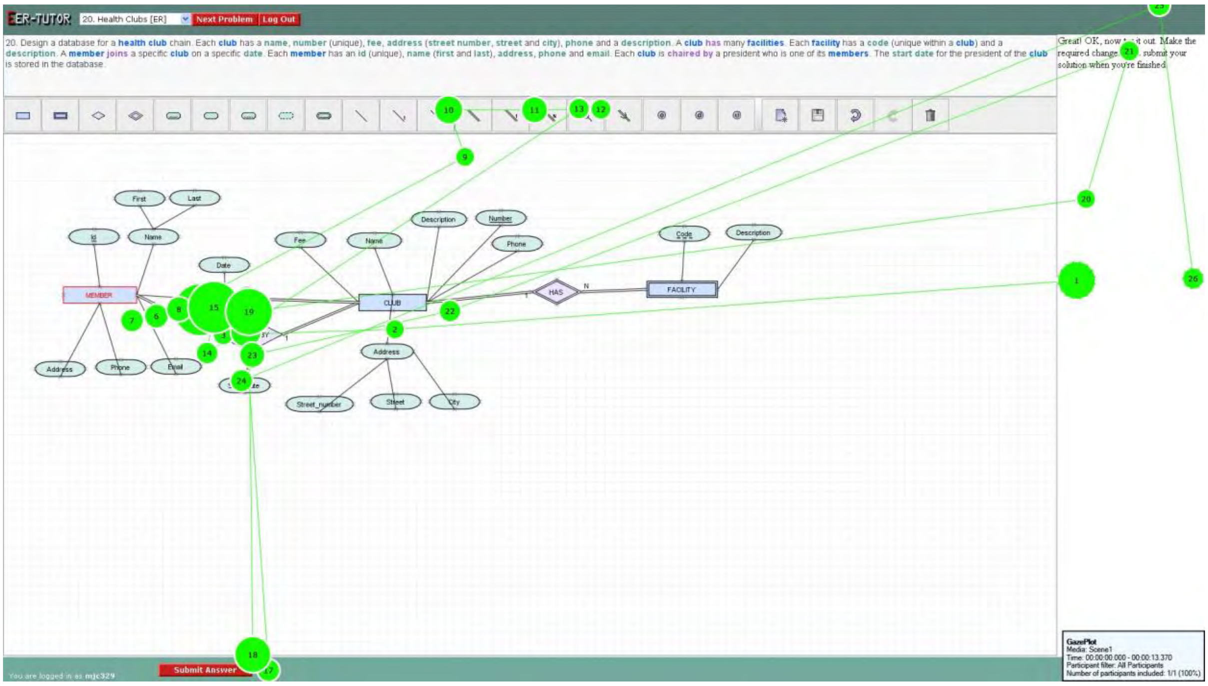

Figure 4. A gaze plot for the *fix* step of the *submit-fix-submit* sequence

Once the student has corrected or attempted to correct the error, ideally s/he should check the rest of the solution before submitting. Students inspected their solutions or rearranged diagram elements prior to submission in 19.8% of segments (Table 1, rows *d*, *h*, *j* and *m*). This kind of behavior was performed by 12 distinct students, at various stages of solution completion, ranging from one participant who checked the solution after each correction (two occasions in total) to a participant who checked the solution irregularly (after six out of 21 dialogues seen).

Table 1. Interaction sequences

	Pattern	**Segments**	**Distinct Students**
a	*submit - fix - submit*	64	20
b	*submit - attempts_fix - problem - submit*	1	1
c	*submit - attempts_fix - wrong_issue - submit*	2	1
d	*submit - fix - check - submit*	16	9
e	*submit - fix - other - submit*	6	4
f	*submit - fix - problem - submit*	1	1
g	*submit - fix - similar - submit*	5	3
h	*submit - attempts_fix - other - check - submit*	1	1
i	*submit - fix - related - other - submit*	3	3
j	*submit - fix - similar - check - submit*	2	2
k	*submit - fix - similar - other - submit*	1	1
l	*submit - fix - wrong_issue - other - submit*	1	1
m	*submit - fix - related - other - check - submit*	1	1

Following the submission of a correct solution, EER-Tutor gives a final feedback message: "*That's correct, well done!*" From the eye-tracking data, we noticed that 59% of students who completed the problem read the feedback message whereas 24% only briefly looked in its direction. We had expected students to reflect on their correct solutions, but only 18% of students looked at and/or moved the cursor around the canvas or problem statement.

4. Conclusions and Future Work

Understanding students' interactions with an ITS allows us to improve the systems as well as our pedagogical practices. We presented a study in which we investigated how students interact with tutorial dialogues in EER-Tutor, using eye-tracking data. When a student submits a solution for checking, EER-Tutor selects an error to be discussed via a tutorial dialogue. We analysed the effect of the dialogue on the student's actions following the dialogue.

We found that most participants fixed the error discussed in the tutorial dialogue, and asked for feedback immediately. By focusing on the discussion of a single error, we may be encouraging this *submit-fix-submit* pattern. We also observed that students did not always reflect on their solutions after correcting the discussed error or successfully solving the problem. There are therefore opportunities for reflection that students do not take advantage of. If the system can identify the lack of reflection, (e.g. by identifying missed opportunities to improve the solution by fixing similar errors), the system can prompt the student to reflect and make these further changes. In addition, if the student demonstrates repeated behavior patterns, it may be beneficial to point out this behavior and to emphasize the importance of reflection. When analyzing the data from the study we also identified several minor improvements to the wording used in problems and dialogues used in the study.

Eye tracking provides a wealth of information which allows for further improvement of ITSs. We discussed a situation when the student did not understand a tutorial dialogue and was confused as the result. In such situations, the ITS could provide additional support, in the form of examples or additional explanations. Our future work will involve further studies of student behavior in EER-Tutor and enhancements to the system.

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