How to Make Instructional Explanations in Human Tutoring More Effective

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Abstract

Although tutoring is often dominated by tutor-generated explanations, they are rarely beneficial to tutees' learning. In line with previous research, the relative ineffectiveness of tutorial explanations might be attributed to tutors' insufficient skills in assessing tutees' understanding. We conducted an experiment in which we tested whether the effectiveness of tutor-generated explanations can be enhanced by helping tutors to assess the tutees' prior knowledge. We compared a condition in which tutors received explicit information about the tutees' prior knowledge (n = 15 dyads) and a condition without such help (n = 15 dyads). Results showed that tutees in both experimental conditions did not differ with respect to the acquisition of declarative knowledge. However, tutees whose tutors were provided with knowledge information were better able to apply their newly acquired knowledge to novel problems. In addition, these tutees also had fewer false beliefs about the concepts being applied. With respect to tutees' question-asking, we found that instructional explanations generated by tutors with knowledge information reduced the incidence of questions that tutees returned in response to the tutors' explanations. The findings demonstrate that the effectiveness of tutor explanations depends on how well tutors adjust their explanations to the tutees' individual knowledge prerequisites.

Keywords: computer-mediated communication; instructional explanations; question-asking; skill assessment; tutoring

Introduction

There is ample empirical evidence that human one-to-one tutoring is a very effective means of instruction. It has been shown to be superior, for example, to traditional classroom teaching (e.g., Cohen, Kulik, & Kulik, 1982) and intelligent tutoring systems (e.g., du Boulay & Luckin, 2001). Many studies have investigated the factors being responsible for the effectiveness of human tutoring. It has been demonstrated that one important source of its superiority lies in the interactive nature of the tutorial dialogue (e.g., Graesser, Person, Harter, & TRG, 2001; Wood, Wood, & Middleton, 1978). Learning is particularly enhanced when tutees do not simply read or listen to an explanation during tutoring, but instead do actively participate in the tutorial dialogue (Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001; Graesser, Person, & Magliano, 1995).

However, despite the accumulating evidence for this interaction hypothesis, it is also well-documented that human tutoring is largely dominated by tutor-generated explanations. Tutors frequently lecture tutees to a great extent without providing them with opportunities to being constructive and active on their own. For example, Chi et al. (2001) found in their study on tutoring in biology that tutors overwhelmingly controlled and crafted the tutorial dialogue. In the majority of cases, tutors exclusively focused on pursuing the explication of knowledge they thought the tutees needed to know and gave long-winded didactic explanations often unsolicited by the tutees. As a result, the tutor-generated explanations had no substantial impact on tutees' knowledge acquisition. Similarly, VanLehn, Siler, Murray, Yamauchi, and Baggett (2003) analyzed tutorial explanations in the domain of physics. They showed that tutor-generated explanations were seldom beneficial to tutees' understanding. Only in a few cases, the explanations helped tutees to learn principles required for solving physics problems.

These results give rise to the question of why instructional explanations in tutoring only rarely contribute to tutees' learning and understanding to a substantial degree. Chi, Siler, and Jeong (2004) hypothesized that for tutors' explanations to be effective it is necessary that tutors are capable of accurately diagnosing tutees' understanding. Only on the basis of a detailed mental model about the tutee's particular knowledge and misconceptions would tutors be able to adapt their explanations to the individual tutee. However, when asked to assess the tutees' understanding, Chi et al. found that tutors had great difficulties in estimating what the tutees actually did know. They tended to overestimate tutees' correct knowledge and underestimate their incorrect knowledge. Similarly, Nathan and Petrosino (2003) investigated teachers' ability to predict students' difficulties with mathematical problems. Regardless of their educational experience, teachers with high domain knowledge generally overestimated the students' knowledge required to solve symbol-based mathematical tasks. Putnam (1987) analyzed the extent to which tutors used knowledge about their tutees in order to select appropriate tasks for them. He found that tutors seldom diagnosed tutees' understanding. Tutors rather followed in their presentation of problems the "subject matter logic" of a standard curriculum script (see also Graesser et al., 1995).

Altogether, the results provide evidence that tutors have insufficient skills in diagnosing tutees' knowledge. Therefore, when tutors are not able to accurately assess tutees' specific needs, they cannot generate effective explanations, that is, explanations that are adaptive and responsive to the tutees' individual understanding (Leinhardt, 2001). However, adaptive instructional explanations could have a number of benefits for tutees and therefore be a valuable complement to other, more self-guided learning activities in tutoring such as self-explaining (Chi et al., 2001). First, instructional explanations as compared to self-explanations are often preferred by learners (cf. Aleven & Koedinger, 2000; Schworm & Renkl, 2006). Therefore, it seems reasonable to satisfy the tutees' needs by providing them, at least to a certain extent, with instructional explanations. This recommendation is in line with the observation that tutor-generated explanations are prevalent in human tutoring, particularly in computer-mediated contexts (Shah, Evens, Michael, & Rovick, 2002). Secondly, instructional explanations given by tutors are in the great majority of cases correct. In contrast, self-explanations can be incorrect, the result being that wrong knowledge is learned (Renkl, 2002). Thirdly, instructional explanations can help learners to detect inconsistencies in their own understanding and thus prevent them from being caught by an illusion of understanding that might inhibit further learning (Chi, DeLeeuw, Chiu, & LaVancher, 1994). And finally, when learning new material, learners might have comprehension impasses that they cannot resolve on their own. Thus, instructional explanations might compensate for these difficulties by providing additional information that fills gaps in the learners' understanding (VanLehn et al., 2003).

Given the benefits of instructional explanations for learning, it seems sensible to support tutors in providing effective explanations to tutees. One way to do this is to help tutors to form a more elaborate mental model about the tutee's individual understanding (a so-called *student model*, Putnam, 1987). Accordingly, when tutors have a more precise idea of what a tutee does and does not know, it should be easier for them to tailor their instructional explanations to the tutee's specific needs (Chi et al., 2001; Nickerson, 1999; Nückles, Wittwer, & Renkl, 2005). This should benefit tutees' learning because on the basis of such adapted explanations tutees should be better able to construct an appropriate model of the content being explained.

In order to test whether supporting tutors in forming a detailed student model indeed increases the effectiveness of their instructional explanations, we conducted an experiment in which we analyzed tutoring in clinical psychology under two experimental conditions: During tutoring, we did or did not support tutors in constructing a student model by providing them with explicit information about the tutee's background knowledge in clinical psychology. As computer-mediated tutoring is becoming increasingly common and instructional explanations are particularly prevalent in this context (cf. Shah et al., 2002), tutors and tutees in our experiment communicated with each other through a text-based computer interface. Using this experimental scenario, we investigated the effects of tutor-generated explanations on tutees' learning and question-asking.

Research Questions and Predictions

Learning Hypothesis

If tutors are provided with information about a tutee's knowledge level, they should be better able to adjust their instructional explanations to the tutee's particular needs. This adaptation should facilitate tutees' knowledge acquisition. If tutors do not receive any information about the tutee's knowledge, they have lower chances to tailor their explanations to the tutee's knowledge prerequisites. Such suboptimal explanations should impair tutees' learning and understanding. We therefore predicted that tutees should acquire more correct and less incorrect knowledge when they received explanations from tutors who were provided with knowledge information as compared with tutees whose tutors had no knowledge information available.

Question-Asking Hypothesis

As tutees who were tutored with no knowledge information were expected to receive explanations that only insufficiently matched with their knowledge prerequisites, they should experience more discrepancies between the information provided and their own informational needs (Graesser & McMahen, 1993). This should provoke the tutees to write back to the tutor and ask for clarifications or further information more often. When information about the tutee's knowledge level helps tutors to better adapt their explanations to the tutees' knowledge, the tutee should be more content and therefore return fewer questions to the tutor. Thus, it was predicted that tutees would ask substantially more questions when tutors had no knowledge information available, as compared with tutees whose tutors were provided with knowledge information.

Method

Participants

Thirty tutors and 30 tutees participated in the experiment. Tutors were recruited among advanced students of psychology. They had expertise in the domain of clinical psychology, although they had no tutoring experience or training in tutoring skills. We focused on unskilled tutors because the majority of everyday tutors are usually novices (e.g., Fitz-Gibbon, 1977). In order to ensure that all tutors indeed had sufficient knowledge in clinical psychology, they were asked to complete a test that measured their knowledge about different topics in clinical psychology that later would be addressed in the tutoring session. The test consisted of 15 multiple-choice items. On average, all tutors had a fairly high knowledge, $M = 11.23$, $SD = 1.91$ (maximum score to be obtained: 15 points). There were no significant differences between the two experimental conditions, $F(1, 28) = 0.80$, *ns*.

First-year students in psychology served as tutees in the experiment. Both tutors and tutees received 7 EURO per hour for participation.

Design

Tutors and tutees were combined into pairs that were randomly assigned to the experimental conditions. A two-conditions between-subjects design was used with *availability of knowledge information* as the independent variable: (a) tutors were provided with information about the tutee's knowledge (in the following labeled *knowledge information condition*) or (b) tutors were not provided with any information about the tutee's knowledge (*no knowledge information condition*).

Dependent variables encompassed measures of tutees' learning and question-asking. Tutees' learning referred to their declarative knowledge about concepts, their transfer knowledge, and their false beliefs about concepts. Tutees' question-asking was measured by the number of follow-up questions the tutees returned in response to the tutors' explanations.

Materials

The knowledge display The knowledge display provided tutors with information about the tutee's prior knowledge in clinical psychology (see Figure 1). It consisted of three types of information about the tutee that each was displayed on a 3-point scale: (1) general knowledge in clinical psychology, (2) topic-specific knowledge ("attribution theory" and "two-factor theory of phobias"), and (3) knowledge with respect to two specialist concepts relevant to the topic discussed during tutoring (e.g., external attribution, classical conditioning).

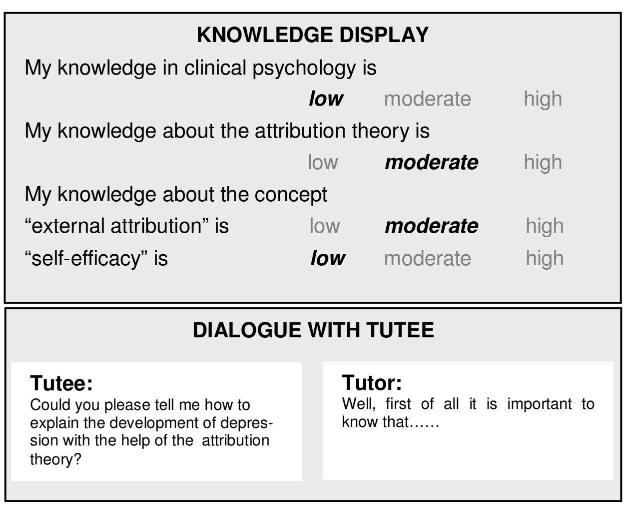

Figure 1: Knowledge display as it was available to the tutors in the knowledge information condition.

The values presented in the knowledge display were determined via an objective assessment procedure. For this purpose, a knowledge test (in the following labeled *knowledge display test*) was developed that contained 6 multiple-choice items representing the general knowledge in clinical psychology, 6 items representing the knowledge about the two-factor theory of phobias, and 6 items representing the knowledge about the attribution theory. The number of items that a tutee had solved correctly in each of the knowledge subtests was translated into values on the corresponding 3-point scales in the knowledge display. For example, if a tutee had solved only 1 or 2 items out of the 6 items of the general knowledge in clinical psychology subtest, this was indicated as a *low* knowledge level. In contrast, if the tutee had solved 5 or 6 items of a subtest, this would be represented in the knowledge display as a *high* knowledge level.

In order to assess the tutee's knowledgeability regarding the specialist concepts, the knowledge display test further asked the tutees to describe the meaning of each of the concepts. A rater scored the written descriptions for correctness by using the 3-point rating scale presented in the knowledge display (see Figure 1).

Tutors' texts In order to refresh tutors' knowledge about the topics being addressed during tutoring, all tutors read – prior to tutoring – two texts that provided them with information about the mental disorders "depression" and "specific phobias" along with psychological models explaining the abnormal behaviors ("attribution theory" and "two-factor theory of phobias"). The texts were taken from the German version of the book "Abnormal Psychology" written by Ronald J. Comer (2001). In the tutoring session, the texts were removed and thus no longer available to the tutors.

Tutees' texts Prior to tutoring, tutees read two texts that provided them with general information about the mental disorders "depression" and "specific phobias". The texts served as an introduction to both mental disorders that were later addressed in the tutoring session. They were presented online on the tutees' computer screen.

Topics addressed in the tutoring session In the tutoring session, tutors and tutees discussed about the mental disorders "depression" and "specific phobias". In order to initiate the dialogue with the tutor, tutees received two prepared inquiries they directed one after another to the tutors. The inquiries required the tutor to explain the mental disorders "depression" and "specific phobias" with the help of the attribution theory and the two-factor theory of phobias, respectively.

Pre- and posttest The pretest *declarative knowledge about concepts* consisted of 10 multiple-choice items that required tutees to answer questions with respect to different concepts relevant to the attribution theory and the two-factor theory of phobias (e.g., "What does internal attribution mean?").

The posttest consisted of the same task. In addition, five open questions were devised to test tutees' ability to apply their knowledge about the attribution theory and the two-factor theory of phobias to new clinical cases (e.g., "Please explain how Elke's fear of flying developed."). These questions measured tutees' *transfer knowledge* (for a similar classification, see Chi et al., 2001).

Procedure

The experiment lasted about three hours and was divided into three sessions given in sequence – the pretest session, the tutoring session, and the posttest session.

In the pretest session, tutees were asked to complete the knowledge display test and the pretest that measured their declarative knowledge about concepts. The experimenters analyzed the knowledge display test in a separate room, where they subsequently entered the results into the knowledge display form (see Figure 1).

In the tutoring session, the tutor and tutee sat in different rooms and communicated through a text-based interface. In the experimental condition, the knowledge display with information about the tutee's knowledge was incorporated into the interface and visible on the tutors' screen (see Figure 1). The tutors were informed that the tutee's knowledge had been determined in advance and that they should try to bear in mind the knowledge information when answering the tutees' questions. The tutee's task was to sequentially direct each of the two prepared inquiries verbatim to the tutor by typing the prepared wording of the inquiry into the text form of the interface. The tutor was asked to answer each inquiry as well as possible. The tutees were free to write back and ask as many follow-up questions as needed. When the tutee addressed the second topic by asking the second prepared inquiry, the knowledge display was automatically updated with regard to the tutee's topic-specific knowledge and the knowledge about the specialist concepts relevant to the current topic.

After tutoring, the tutees again answered the test on declarative knowledge about concepts. In addition, tutees completed the transfer knowledge test that required them to apply their newly acquired knowledge to clinical cases.

Analyses and Coding

Declarative knowledge about concepts In the pre- and posttest that measured tutees' declarative knowledge about topic-specific concepts, each correct answer was assigned 1 point. As both the pretest and the posttest consisted of 10 multiple-choice items, the maximum score was 10 points.

Transfer knowledge Tutees' answers to the transfer questions were scored for correctness. For this purpose, we constructed a reference answer for each of the five questions. As the maximum score to be obtained was slightly different for each of the five questions, the points a tutee earned for each question were divided by the maximum score that was obtainable for each question. Thus, the score of the transfer knowledge test was represented by the percentage of points achieved by a tutee.

False beliefs All answers that tutees gave in response to the transfer knowledge questions were coded for false beliefs. For this purpose, a blind rater coded whether a tutee incorrectly applied the concepts of the attribution theory or the two-factor theory of phobias to the new clinical cases (e.g., "The fear of flying is caused through an avoidance behavior", for a similar classification, see Chi et al., 2004).

Follow-up questions The dialogues between tutors and tutees were recorded. The follow-up comprehension questions that tutees asked in response to a tutor's explanation were counted.

Results

Tutees' Learning

In order to examine tutees' knowledge acquisition, we differentiated between three types of knowledge: declarative knowledge about topic-specific concepts, transfer knowledge, and false beliefs. Following the *learning hypothesis*, in the condition where the tutors had information about the tutee, the tutees should acquire more correct and less incorrect knowledge than tutees in the no knowledge information condition. Table 1 shows the mean values of tutees' declarative knowledge about concepts (pre- and posttest), their transfer knowledge, and false beliefs. In order to examine tutees' acquisition of declarative knowledge on the concepts discussed during tutoring, we performed a repeated measures analysis with tutees' pre- and posttest gains as the within-subjects factor and experimental condition as the between-subjects factor. The analysis revealed that tutees in both experimental conditions displayed a high knowledge gain, $F(1, 28) = 70.26$, $p < .001$, $\eta^2 = .72$ (strong effect). However, there was neither a main effect for experimental condition, $F(1, 28) = 0.37$, *ns*, nor an interaction effect, $F(1, 28) = 1.00$, *ns*. Evidently, tutees in both experimental conditions acquired declarative knowledge about the concepts to a similar extent.

In a next step, we analyzed tutees' transfer knowledge and false beliefs. To this purpose, we performed separate ANOVAs. The results clearly supported our prediction. Tutees whose tutors had knowledge information available more often correctly applied their knowledge to solve clinical cases as compared with tutees in the no knowledge information condition, $F(1, 28) = 9.51$, $p = .001$, $\eta^2 = .25$ (strong effect). In addition, they had significantly less misunderstandings about the concepts to be applied than tutees who were tutored with no knowledge information, $F(1, 28) = 10.98$, $p = .003$, $\eta^2 = .28$ (strong effect).

Tutees' Question-Asking

Following the *question-asking hypothesis*, tutees should ask fewer questions in response to a tutor's explanation in the knowledge information condition compared with the no knowledge information condition. As there was one tutee in each of the two experimental conditions whose number of follow-up questions was at least 3 standard deviations above the mean, we excluded these two outliers from further calculations. The ANOVA performed on tutees' follow-up questions confirmed the question-asking hypothesis, $F(1, 26) = 5.38$, $p = .03$, $\eta^2 = .17$ (strong effect). Tutees in the knowledge information condition asked significantly fewer follow-up questions than tutees in the no knowledge information condition (see Table 1). When the two outliers were not excluded but instead replaced by scores that were one unit larger than the next extreme score (for details of this procedure, see Tabachnick & Fidell, 1996), a similar result was found, $F(1, 28) = 4.24$, $p = .049$, $\eta^2 = .13$ (medium to strong effect).

Table 1: Means and Standard Deviations (in Parentheses) of the Dependent Variables of the Experiment.

	Experimental Condition	
Dependent Variable	Knowledge information condition	No knowledge information condition
Tutees' pretest scores on declarative knowledge about concepts	3.67 (2.86)	2.80 (2.54)
Tutees' posttest scores on declarative knowledge about concepts	6.87 (2.17)	6.87 (1.19)
Tutees' transfer knowledge (in %)	86.27 (23.15)	62.72 (18.42)
Number of tutees' false beliefs	1.13 (1.19)	4.11 (3.26)
Number of tutees' follow-up questions during tutoring	3.14[a] (1.96)	4.86[a] (1.96)

Note. [a]The means and standard deviations are computed on the basis of only 14 tutees in each of the two experimental conditions, because there was one outlier in each experimental condition that was excluded from further calculations.

Discussion

This study showed that supporting tutors in adapting their explanations to the tutees' knowledge improved the effectiveness and efficiency of tutoring. Tutees whose tutors were provided with information about their background knowledge benefited more from the instructional explanations than tutees who were tutored with no knowledge information. As a result, the tutees were not only better able to apply their newly acquired knowledge to solve clinical cases but also displayed fewer misunderstandings about the concepts being applied. At the same time, the efficiency of tutoring was raised in the knowledge information condition because the tutees directed fewer follow-up questions to the tutors, which shows that they obviously experienced fewer difficulties in comprehending the tutors' explanations. These findings are in line with the study conducted by Nückles et al. (2005) who found, in the context of computer counseling, that laypersons acquired more knowledge and asked fewer questions when experts were presented data about the layperson's knowledge level as compared to control conditions with no knowledge information (for similar results, see Nückles, Winter, Wittwer, Hübner, & Herbert, in press). Evidently, when tutors (or experts) have only an imprecise mental model about the tutees' individual understanding, they produce explanations that do not effectively support tutees' knowledge acquisition and more often lead to comprehension breakdowns. This is corroborated by empirical findings that demonstrate the negative effects on communication when interlocutors misjudge the partner's knowledge. For example, Wittwer, Nückles, and Renkl (2005) investigated the consequences for laypersons' learning and question-asking when experts overestimated or underestimated a laypersons' understanding. Results showed that laypersons' learning from experts' explanations was impaired when experts had biased estimates of the laypersons' knowledge. In addition, both overestimated and underestimated laypersons asked more questions as compared with laypersons tutored by experts who had valid knowledge information about the layperson available.

With respect to the acquisition of declarative knowledge, we found no significant differences between the experimental conditions. Obviously, the instructional explanations generally helped tutees to accumulate a fairly similar stock of knowledge about topic-specific concepts, irrespective of whether the explanations were generated by tutors with or without knowledge information. However, the results on tutees' transfer knowledge showed that explanations generated by tutors with knowledge information more effectively supported tutees in using their knowledge to solve clinical cases. This finding suggests that explanations that are tailored to the tutee's specific needs are more beneficial to the acquisition of deep knowledge (i.e., knowledge to be applied to novel situations) than to the acquisition of more shallow knowledge (i.e., declarative knowledge that is directly stated in the tutors' explanations). This conjecture is consistent with findings of text revision studies that show that adjusting instructional texts to a readers' prior knowledge level often benefits only the readers' deep understanding and not their shallow learning (e.g., McNamara, Kintsch, Songer, & Kintsch, 1996). Apparently, adaptive explanations particularly facilitate the integration of new information into a coherent and well-integrated mental representation of the content being explained in the form of a situation model (Kintsch, 1998). On the basis of such a situation model, tutees might be better able to generate inferences and thereby better able to apply their knowledge.

Moreover, the result that instructional explanations given by tutors who were provided with knowledge information reduced the number of tutees' false beliefs about topic-specific concepts demonstrates that adaptive explanations can substantially help to prevent tutees from acquiring incorrect knowledge. This finding is of particular importance for tutoring because research has shown that tutors are dismal at assessing tutees' misunderstandings (e.g., Chi et al., 2004). However, when tutors are not able to diagnose tutees' incorrect knowledge, tutee's false beliefs do persist and will not be removed. Hence, the provision of instructional explanations that are adapted to the tutees' individual knowledge would not only lower the chances of learning wrong knowledge but also make a continuous diagnosis of tutees' false beliefs less necessary. Compared with other more self-guided knowledge-construction activities, adaptive instructional explanations would also be of relevance whenever tutees cannot generate a sufficient explanation by themselves or are particularly prone to learn wrong knowledge (Renkl, 2002).

All in all, the present study shows that tutorial explanations should not be condemned as being an ineffective means of instruction per se. Rather, their effectiveness largely depends on how well tutors are able to adjust their explanations to the tutees' individual needs (Chi et al., 2001; Leinhardt, 2001). In so doing, tutors make instructional explanations a valuable complement to other learning opportunities that exclusively focus on tutees' own meaningful construction of knowledge.

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