The Effect of Friendship and Tutoring Roles on Reciprocal Peer Tutoring Strategies

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Abstract. Intelligent Tutoring Systems that employ a teachable agent or reciprocal tutoring agent are designed to elicit the beneficial effects of tutoring, known as the tutor learning effect. However, untrained tutors do not spontaneously use beneficial tutoring strategies, and in a reciprocal format, it is unclear how the tutor learning effect affects those tutors' future problem-solving. Here, we examine the effect that the relationship between tutor and tutee has on their likelihood to use various tutoring and learning strategies, and the impact those strategies have on tutees' future problem-solving in a reciprocal format. We find that among friends, tutees tend towards more verbalization of their problem-solving, with their tutors adopting a more questioning tutoring style, while among strangers, tutees use more shallow questions, with more procedural instruction from their tutor.

Keywords: Tutor learning effect · Reciprocal tutoring · Peer tutoring

1 Introduction and Related Work

Teachable Agents (TAs) have been proposed as a scalable way to achieve the benefits of learning-by-teaching that have been seen in human tutoring dyads, where the tutor benefits from the interaction as much or more than the tutee. This is also known as the tutor learning effect [5,9,11]. The fixed-role design of current TAs, however, may not elicit the tutor learning effect if the tutor does not have sufficient prior knowledge to tutor, or if they lack the opportunity to apply what they learned while subsequently problem-solving as a tutee. To address this gap, "reciprocal tutoring agents" have been proposed that can both tutor and be tutored by the student [3,8]. To implement such a system effectively, we must first understand how the use and impact of specific tutoring and learning strategies differs for the tutor and tutee when tutoring in a reciprocal format, as prior research on both TAs and reciprocal tutoring often lacks the fine-grained interaction data necessary to understand the tutor learning effect [5,7,10–12,14].

In this paper, we examine how tutors' and tutees' explanations during the tutoring sessions incorporate knowledge-building (e.g. elaborated explanations of conceptual knowledge) or knowledge-telling (e.g. summarization with little monitoring or elaboration) [11]. We also follow [6] in examining the questions

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asked by the tutors and tutees, both deep (e.g. probing their partner for conceptual understanding) and shallow (e.g. asking about procedures or answers). Additionally, prior work suggests that the particular discourse styles of friends provide unique resources for problem-solving and learning [1], indicating that the rapport between friends that allows them to disagree without consequences may account for their ability to foster more mature thinking in one another. If this is true, we want to understand to what extent the relationship between the tutor and tutee affects their use of beneficial tutoring and learning strategies, particularly because TAs (and perhaps reciprocal tutoring agents) rely on the "protégé effect," which evokes in tutors a feeling of responsibility for their virtual student [2,4,8].

This paper expands on prior work by (1) providing a fine-grained, utterance-level analysis of the ways that explanations and questions are used by tutors and tutees of differing relationship statuses. (2) We then shed light on whether and how, in a reciprocal tutoring format, the "tutor learning effect" still holds, to understand whether a tutor's future problem-solving is more affected by the explanations and questions they use while a tutor, those their tutor uses, or those they use while problem-solving as a tutee.

2 Methodology

Research Questions. *RQ1*: How frequently do peer tutors and tutees use knowledge-telling, knowledge-building, shallow and deep questions, and metacognitive reflection, and how does that use differ between friend and stranger dyads? Following prior literature we hypothesize that tutors will explain more than tutees, and tutees will question more than tutors [14], and that all participants will use more knowledge-telling than-building and ask more shallow than deep questions [6]. We also hypothesize that dyads of strangers are less likely than friends to use knowledge-building and metacognitive reflection, due to the social risks from explaining incorrectly or reflecting on one's knowledge in front of a stranger [1,11].

RQ2: Which has more impact on a tutee's problem-solving strategies: the tutoring strategies they used in the prior period when they were a tutor, the learning strategies they use as a tutee trying to solve those problems, or the tutoring strategies their tutor uses? Perhaps counter-intuitively, our hypothesis, based on the benefits seen from the tutor learning effect, is that the knowledge-building, deep questions, and metacognitive reflection used while tutoring will better predict correctly solved problems in those tutors' subsequent problem-solving than the strategies their tutors use while teaching them, or the strategies they use while problem-solving [12,14,15].

Dialogue Corpus. Our corpus comprises interaction data from 10 peer dyads (mean age 13.4, SD = 1.1), reciprocally tutoring one another in algebra for 4 weekly hour-long sessions. Each session was split into two tutoring periods, with students switching tutoring roles after each period. Half the dyads were boys,

Table 1. Tutoring and learning strategy codes, definitions, and examples

Code	Definition	Example
`Knowledge-telling`	Stating numbers, variables, procedures, or the answer.	Divide it by 9.
`Knowledge-building`	Providing elaborated explanations of the idea, concept, or reasoning.	That's because it can be reduced.
`Metacognitive Reflection`	Verbally reflecting on their or their partner's knowledge.	What I don't understand is what we do with the p.
`Shallow Question`	Asking for confirmation of an answer, a definition, or an example.	Do I move the numbers first?
`Deep Question`	Asking about reasoning, concepts, or hypotheticals.	What do you think you would do with this side?

and half girls to mitigate the stereotype threat seen in mixed-gender tutoring dyads [10]. Half the dyads self-defined as friends and half as strangers prior to the tutoring session. Video and audio data were recorded for each session, transcribed, and segmented by clause. Following [6,11], five annotators coded the corpus for explanations, questions, and reflection used by either the tutor and tutee, as explained in Table 1 (all Krippendorff's $\alpha > .7$). We will refer to these as tutoring strategies when used by the tutor, and learning strategies when used by the tutee. The corpus was also coded for off-task utterances ($\alpha = .75$).

Learning Outcome Measures. Each student took a pre-test in the first session with 20 procedural questions, and after the final session, a counterbalanced, isomorphic post-test. The tutees were given 10 problems to solve in each tutoring period, scored as 1 if successfully completed in its entirety, and 0 if not. Because in this analysis we desire to associate strategies used in each tutoring period with an outcome measure for that same period, we used the problem-solving performance in each period as our measure of learning, instead of gains from pre- to post-test.

3 Results

Descriptive Statistics. The mean percent of problems successfully solved across all sessions was .63 (SD = .38), with no significant difference for gender or relationship. Although friends talked more than stranger dyads overall, and friends had more off-task talk than strangers, interestingly, there was no significant difference in their on-task talk. See Table 2 for means and standard deviations of friend and stranger dyads' utterances.

RQ1: Frequency of Tutoring Strategies. Because of individual variation in number of utterances (particularly social talk), we analyzed each tutoring and

Table 2. Means and Standard Deviations of Utterance Counts, with p value from a t-test of friend and stranger dyads.

	All dyads	Friends	Strangers	Significance
`All Utterances`	144 (81.7)	178 (82.1)	109 (65.6)	$p < .001$
`Off-task`	37 (83)	67 (106)	7.4 (28.9)	$p < .001$
`On-task`	127 (65.6)	136 (67.1)	120 (63.6)	Not sig.

learning strategy as a percentage of all on-task utterances, for all dyads, and for each of the four combinations of tutoring role and relationship (See Table 3 for means and standard deviations). As we expected, for all dyads, knowledge-telling was used more frequently than knowledge-building, and shallow questions more than deep questions. However, the variations in those initial results led us to explore interaction effects between gender, relationship, and role for tutoring and learning strategies. We therefore conducted a series of 5 repeated measures ANOVAs. For each of the 5 strategies, we crossed the between-subjects factors of gender (M/F) and relationship (Friend/Stranger) with the within-subject, repeated measures of role (tutor/tutee) and session (1–4) for a $2 \times 2 \times 2 \times 4$ ANOVA, with Dyad, Role, and Session as error terms. We employed a Bonferroni correction to account for running multiple tests.

The ANOVA for knowledge-building revealed a significant main effect for role ($F(3,18) = 12.2$, $p < .05$), with tutors using more knowledge-building than tutees, as expected. The ANOVA for knowledge-telling revealed significant interaction effects for role by relationship ($F(3,18) = 4.6$, $p < .05$), with friend tutees using more knowledge-telling than friend tutors, while stranger tutors used more than stranger tutees. The ANOVA for shallow questions revealed a significant main effect for role ($F(3,18) = 21.7$, $p < .01$), with tutees asking more shallow questions than tutors, as expected. There was also an interaction effect for role by relationship ($F(3,18) = 19.8$, $p < .01$), with stranger tutees asking more shallow questions than friend tutees, and friend tutors asking more than stranger tutors. The ANOVA for deep questions and metacognitive reflection revealed no significant main or interaction effects.

Table 3. Means and standard deviations of tutoring and learning strategies

	Knowledge-telling	Knowledge-building	Metacognitive reflection	Shallow questions	Deep questions
`All Dyads`	0.44 (0.18)	0.04 (0.06)	0.04 (0.04)	0.08 (0.08)	0.01 (0.02)
`Friend Tutees`	0.42 (0.19)	0.02 (0.02)	0.05 (0.05)	0.08 (0.06)	0.01 (0.02)
`Stranger Tutees`	0.46 (0.20)	0.03 (0.05)	0.03 (0.02)	0.13 (0.11)	0.01 (0.02)
`Friend Tutors`	0.38 (0.12)	0.03 (0.04)	0.05 (0.04)	0.07 (0.04)	0.01 (0.02)
`Stranger Tutors`	0.38 (0.13)	0.09 (0.08)	0.03 (0.02)	0.03 (0.03)	0.01 (0.02)

RQ2: Effect of Tutoring and Learning Strategies on Problem-Solving in Reciprocal Tutoring. Our hypothesis (from the tutor learning effect) was that the tutoring strategies that participants used while tutoring in period 1 (T_1) would be more predictive of their problem-solving in the subsequent period (T_2) when they are the tutee, than the strategies their tutor uses to teach them in T_2. It is therefore necessary to separate the effect of the tutoring strategies that a given participant (e.g. P_1) used while tutoring (P_1, T_1) on their subsequent problem-solving in T_2, from the effect of the tutoring strategies that *their* tutor (P_2, T_2) used while P_1 was problem-solving. We also wanted to distinguish both of those effects from the effect of the explanations and questions that they (P_1) used while problem-solving (P_1, T_2).

We thus created three sets of linear mixed effect models. In all models, we set as fixed effects the pre-test percent, gender, and relationship, and set as random effects the dyad and the session. We also included as fixed effects in model (1) the learning strategies used by the tutee (P_1, T_2); in model (2) the strategies used by the same participant when they were previously the tutor (P_1, T_1); and in model (3) those strategies used by that participant's tutor (P_2, T_2).

After running each of the three mixed-effect models, we used pairwise ANOVAs to compare each model's ability to predict the tutee's problem solving. As hypothesized, Model 2 (P_1, T_1; the "prior tutoring" model), was more predictive ($\chi^2(15) = 4.7$, $p < .001$) than Model 3 (P_2, T_2; the "current tutor"). Interestingly, Model 1 (P_1, T_2; the "current tutee" model) was in fact more predictive ($\chi^2(12) = 7.4$, $p < .001$) than Model 2 (P_1, T_1; the "prior tutoring" model), and it was also more predictive ($\chi^2(12) = 8.9$, $p < .001$) than Model 3 (P_2, T_2; their "current tutor").

To better understand the effect of the individual learning strategies used by the tutee, we examined the coefficients of each of the fixed effects for the most predictive model, the current tutee model (Model 1). As expected, the fixed effect of pre-test was significantly predictive of problem-solving, with a coefficient of .31 ($p < .01$). Unexpectedly, however, shallow questions from the tutee were positively predictive (.29), and deep questions were negatively predictive ($-.29$), (both at ($p < .01$)). Knowledge-telling and -building were both positively predictive of problem-solving, but neither was significant.

4 Discussion and Conclusion

We set out to explore the impact that role and relationship have on the use of tutoring and learning strategies, and how variations in that strategy use impacted problem-solving, to identify implications for a teachable agent or reciprocal tutoring system. Although we found that, overall, friends spoke more, and used more off-task utterances than strangers, the amount of on-task talk was equivalent, indicating that friends were supplementing their tutoring talk with social talk, not replacing it. We found that friend tutors asked more questions of their tutees than stranger tutors, indicating a more Socratic questioning style of instruction (e.g., "Two times what equals eight?"). Friend tutees in return used greater amounts of knowledge-telling than their tutors, suggesting that friend

tutors avoided giving direct instruction, while the tutees felt more comfortable verbalizing their problem-solving while working. For instance, a friend tutee said, "okay so that would give you a two... negative two x equals two", allowing her tutor to provide feedback on a step-level instead of simply evaluating the answer. On the other hand, stranger tutees asked more questions than friend tutees, suggesting that strangers had more of a disposition towards answer- or instruction-seeking than friends. For example, from a stranger tutee, "So do I start with the eight or the two?" In return, stranger tutors used more knowledge-telling than stranger tutees, resulting in more procedural instructions. For example, from a stranger tutor, "Add the eight." which was subsequently performed by the tutee. This all suggests further interactional benefits to a relationship or friendship between tutor and tutee.

The surprising negative coefficient that we saw for asking deep questions might be because asking conceptual questions is indicative of that tutee's lack of prior knowledge, or because the tutees received an unsatisfactory response from their tutor to these deep questions. Upon further investigation, the majority of the tutor responses to deep questions were knowledge-telling or a shallow question, instead of the knowledge-building, elaborated response which we would expect to be a beneficial response. More research is needed on how best to provide the structured support needed for untrained peer tutors to provide the elaborated knowledge-building which has been shown to lead to tutor learning, whether that support be from a teachable agent or reciprocal tutoring system. Additionally, our future work will use conceptual items on a repeated pre- and post-test to better understand how tutors' and tutees' conceptual knowledge improves from their use of tutoring and learning strategies, in addition to their problem-solving.

For designers of intelligent tutoring systems, whether for a tutoring agent, a teachable agent, or a reciprocal tutoring agent, it is important to understand the consequences that role and relationship have on the specific tutoring and learning strategies used in the tutoring discourse. With a perceived friendship or rapport between tutor and tutee, the tutee may feel more comfortable verbalizing their problem-solving, allowing for more step-level feedback from the tutor, and tutors may feel more comfortable asking questions about their tutee's problem-solving process instead of simply giving explicit instructions. In this paper, we examined the ways that various types of tutoring and learning strategies are affected by the relationship of the dyad, and their impact on problem-solving. We also offer one approach to untangling the complex interactions between explanations, questions, and problem-solving in a reciprocal tutoring format.

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