Adaptive Support for CSCL: Is it Feedback Relevance or Increased Student Accountability that Matters?

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Abstract: While fixed CSCL support approaches such as collaboration scripts have been shown to improve domain learning, adaptive support that varies based on student actions may be more effective. In this paper, we discuss the Adaptive Peer Tutoring Assistant (*APTA*), an adaptive support system for computer-mediated peer tutoring in high-school Algebra. We conducted an after-school study with 122 participants where we compared *APTA* to two fixed support conditions: one where we told students support was adaptive when it was not, and one where we told students support was fixed. These manipulations explored two hypotheses: Adaptive support is effective because it is relevant to student behaviors, and support that is perceived to be adaptive is effective because it makes students feel accountable for their actions. *APTA* showed better effects on tutor and tutee learning compared to the other conditions, suggesting that the more relevant the support, the more beneficial it will be.

Introduction

Collaborative activities in the classroom can yield positive learning outcomes through the social construction of knowledge (Schoenfeld, 1992), but students need to engage in beneficial reflective and elaborative processes, and generally do not do so without assistance (Lou, Abrami, & d'Apollonia, 2001). Collaboration can be supported using *scripts*, where interaction is structured by assigning students roles and activities to follow in their interaction (e.g., Fischer, Kollar, Mandl, & Haake, 2007). For example, in the reciprocal teaching script for reading comprehension by Palincsar and Brown (1984), students alternate between the roles of tutor and tutee, and engage in a sequence of elaborative activities involving summarizing, questioning, clarifying and predicting. Other script approaches structure student dialogue on a fine-grained level by providing questions (e.g. "What would happen if ...") or sentence starters (e.g. "It was found that ...") that students apply during their collaboration (Kollar, Fischer, & Slotta, 2005). While scripts have been successful, they may not be maximally effective at improving student collaboration: providing too much support for students who do not need it or too little support for students who do (e.g., Kollar et al., 2005). Further, they might have drawbacks because they overstructure student interaction, limiting student control, and potentially reducing feelings of being good collaborators and desire to be good collaborators (Dillenbourg, 2002).

A promising new method for facilitating computer-supported collaborative activities in the classroom is by providing students with *adaptive* collaborative learning support (ACLS), where interaction is analyzed as it occurs and then support is provided tailored to the needs of individual collaborators. The few adaptive support systems that have been evaluated with students have shown benefits compared to fixed support (Baghaei, Mitrovic, & Irwin, 2007; Kumar, Rosé, Wang, & Joshi, & Robinson, 2007). However, because of the technical challenges in developing robust ACLS systems, these evaluations are difficult to conduct, and it is still unclear under what conditions adaptive support is more effective than fixed support. In the study presented in this paper, we explore two mechanisms for the potential effectiveness of adaptive support, illustrated in Figure 1. First, we hypothesize that adaptive support in collaborative learning is effective for the same reasons as in individual learning: it is more relevant than fixed support (*H1: Relevance Hypothesis*). Students might benefit from being able to immediately apply the support to their interaction, leading them to improve their collaboration and their domain learning (Rummel & Weinberger, 2008). Additionally, because support only appears when it is relevant it avoids the overstructuring problem of fixed support, potentially increasing student feelings of being good collaborators (*perceived collaboration efficacy*). A second hypothesis is that students who *believe* that support is adaptive may feel more accountable for their collaborative actions, and thus be more motivated to collaborate effectively (*H2: Accountability Hypothesis*). Accountability for one's partner's outcomes tends to be an important motivational force in collaboration (e.g., Slavin, 1996), and it is plausible to assume that if students believe the computer is responding to their actions, they may feel an increased sense of responsibility for those actions. If this hypothesis is correct, we would see benefits of collaboration on both student goals to be effective collaborators (*collaboration goal orientation*) and domain learning. Distinguishing between these two hypotheses is important because if *H2* is true, it suggests that it may not be necessary to develop sophisticated adaptive systems, but simply to develop systems that can convincingly pretend to be adaptive.

To examine these two hypotheses, we developed a system to adaptively support a reciprocal peer tutoring activity for high school algebra, building on a successful individual intelligent tutoring system, the Cognitive Tutor Algebra *(CTA*; Koedinger, Anderson, Hadley, & Mark, 1997*)*. We conducted a study where we

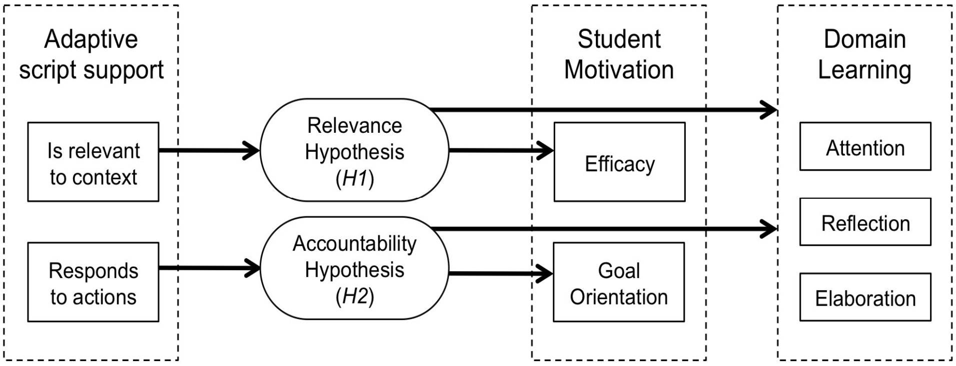

Figure 1. Adaptive support may influence domain learning and motivation by being more relevant to student needs (*H1*), which should enhance self-efficacy and learning, or by encouraging greater accountability (*H2*), which should enhance goal orientation and learning.

compared an adaptive to a fixed support system, by varying the adaptivity of reflective prompts given to peer tutors to improve their help-giving. In order to differentiate between the two hypotheses, and determine whether adaptive support could be solely effective through the *accountability hypothesis (H2),* we included a third condition where we told students support was adaptive, when it in fact was fixed. Student belief that support is adaptive may lead to benefits that can be explained by *H2* but not *H1*. In this paper, we first discuss the reciprocal peer tutoring context for the adaptive support. We then describe the adaptive support system we have developed for reciprocal peer tutoring. Finally, we discuss the study methodology and its results.

Context: Help-Giving in Reciprocal Peer Tutoring

Help-giving is an important part of many collaborative activities, and is a key element of the productive interactions identified by Johnson and Johnson (1990) that contribute to learning from collaboration. The act of giving help has been demonstrated to improve learning of both the help giver and the receiver (see Ploetzner, Dillenbourg, Preier, & Traum, 1999). In giving help, even novice students benefit through *reflective* and *elaborative* processes; they reflect on their peer's error and then construct a relevant explanation, elaborating on their existing knowledge and generating new knowledge (Roscoe & Chi, 2007). In turn, students benefit from receiving good help; that is, help that arrives when they reach an impasse, allows them to self-explain, and, if necessary, provides an explanation that is conceptual, targets their misconceptions, and is correct (Webb & Mastergeorge, 2003). Unfortunately, most students do not exhibit good help-giving behaviors spontaneously (Roscoe & Chi, 2007). Specifically, students are often more inclined to give each other instrumental help (e.g., "subtract *x*"). They rarely provide conceptual, elaborated help that explains why, in addition to what, and references domain concepts (e.g., "subtract *x* to move it to the other side"). This tendency decreases the likelihood that either student benefits from the interaction (Webb & Mastergeorge, 2003). Therefore, promoting conceptual help-giving is a major focus of peer tutoring support. It is one criteria of good help for the receiver, and an indicator that the help-giver engaged in elaborative processes.

One technique for facilitating student help-giving is by employing a reciprocal schema, where students are given different information and take turns helping each other using the information they received (Dillenbourg & Jermann, 2007). As part of their role, helpers must monitor their partner's problem solving and offer appropriate explanations when needed. Examples of this class of collaborative activities are reciprocal teaching by Palincsar and Brown (1984), mutual peer tutoring by King, Staffieri, and Adelgais (1998), and reciprocal peer tutoring by Fantuzzo, Riggio, Connelly, and Dimeff (1989). Reciprocal learning settings have been successful at increasing student learning in classroom environments compared to individual and unstructured controls (Fantuzzo et al., 1989; King et al., 1998; Fuchs et al., 1997), but only when student activities are appropriately supported. For example, Fuchs et al. (1997) trained students to deliver conceptual mathematical explanations and give elaborated help, and showed that their mathematical learning was significantly better than elaborated help training alone or an individual learning control. There is reason to believe that adaptive support would be effective in this context, for the same reasons that it may be effective in other collaborative contexts. Adaptive support might provide relevant assistance at moments when it most needed, increasing student reflective and elaborative processes, and thus improving domain learning. Additionally, motivation plays an important part of peer tutoring. Peer tutors who feel accountable for their partner's learning tend to attend more to the subject material and learn more (e.g., Biswas et al., 2005), and peer tutors who feel like good tutors tend to try harder at the activity (Medway & Baron, 1977). Adaptive support in this context might have an amplified effect on student motivation, enabling us to investigate both the *relevance* and *accountability hypotheses*.

System: The Adaptive Peer Tutoring Assistant

Basic Peer Tutoring Script

To investigate the effects of adaptive collaboration support, we constructed a computer-supported collaborative learning system called the Adaptive Peer Tutoring Assistant (*APTA*). In *APTA*, dyads of students work on literal equation problems where they are given an equation like "$ax + by = c$" and a prompt like, "Solve for x". Students are seated at different computers, and at any given time, one student is the peer tutor and the other is the tutee. Tutees can perform operations on the equation with a menu-based interaction used in the common, individual version of the Cognitive Tutor Algebra (*CTA*). Using the menus, students can select operations like "subtract from both sides", and then type in the term they would like to subtract. For some problems, the computer then performs the result of the operation and displays it on the screen; for others, the tutee must type in the result of the operation themselves. The peer tutors can see the tutee's actions on their computer screen, but are not able to perform actions in the problem themselves (#5 in Figure 2). Instead, the peer tutor can mark the tutee's actions (#6 in Figure 2), and adjust tutee skill assessments in the skillometer window (#1, Figure 2). Students can discuss the problem in a chat window (#4 in Figure 2). We intended that in constructing help for tutees in the chat window, peer tutors would engage in elaborative aspects of tutoring, generating knowledge and integrating it with existing knowledge. To facilitate the discussion in the chat window, we included a common form of fixed scaffolding: sentence classifiers. This form of fixed scaffolding is thought to be pedagogically beneficial by making positive collaborative actions explicit in the interface and encouraging students to consider the type of utterance they wish to make (Weinberger, Ertl, Fischer, & Mandl, 2005). We asked peer tutors to label their utterances using one of four classifiers: "ask why", "explain why wrong", "give hint", and "explain what next" (#8 in Figure 2). Students had to select a classifier before they typed in an utterance, but they could also choose to click a neutral classifier ("other"). For example, if students wanted to give a hint, they could click "give hint" and then type "subtract x". Their utterance would then appear as "tutor hints: subtract x" to both students in the chat window. By making those behaviors explicit in the interface, we hoped to encourage students to put more consideration into what they said and why, facilitating them in constructing more conceptual help.

In the basic version of *APTA*, we provided tutors with adaptive domain assistance that supported them in reflecting on tutee errors. We intended that this assistance have the additional benefit of ensuring that the

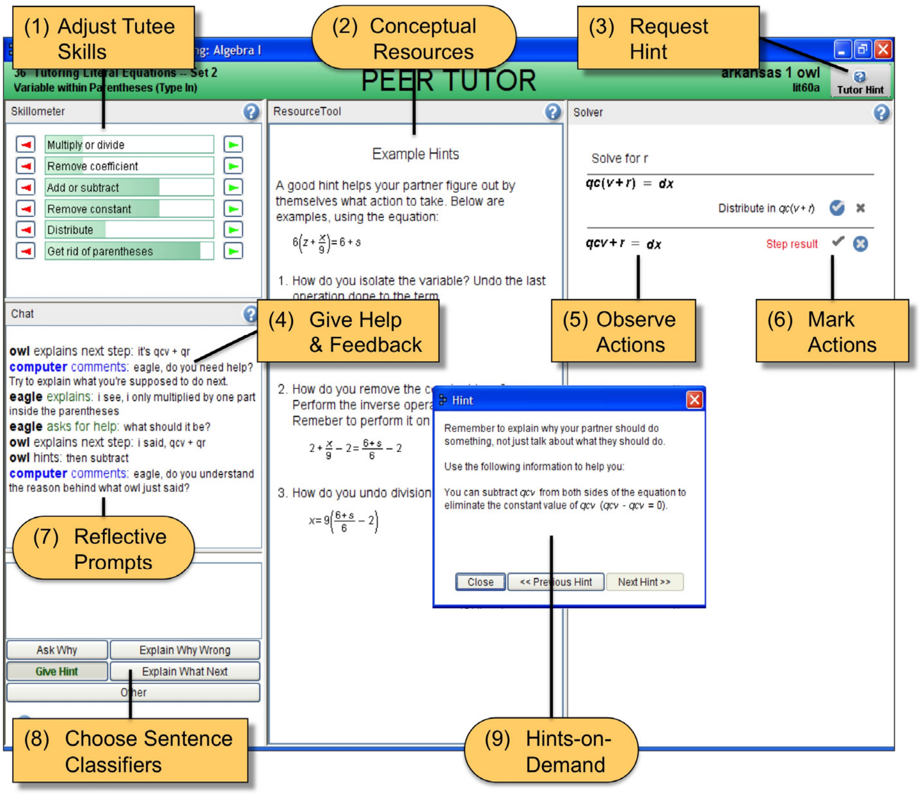

Figure 2. Peer tutor's interface in *APTA*. Tutors observe and mark tutee actions, assess tutee skills, and provided tutees with explanations in the chat window. They receive domain hints and feedback, and adaptive reflective prompts to help them improve their collaboration.

tutee received more correct help than they otherwise would have. This assistance was provided in two cases. First, the peer tutor could request a hint from the CTA and relay it to the tutee. Second, if the peer tutor marked something incorrectly in the interface (e.g., they marked a wrong step by the tutee correct), the intelligent tutor would highlight the answer in the interface, and present the peer tutor with an error message. Hints and error messages were composed of a collaborative component ("Remember to explain why your partner should do something, not just what they should do"), and the cognitive component that the tutee would have originally received had they been using the CTA individually ("You can subtract *qcv* from both sides of the equation to eliminate the constant value of *qcv* [*qcv* – *qcv* = 0]"; see #9, Figure 2). If the tutor clicks next hint, both components become more specific, until the cognitive component reveals the answer to the tutor.

Reflective Prompts: Study Manipulation

Our experimental manipulation varied the adaptivity of reflective prompts students receive while collaborating. These reflective prompts appear simultaneously to both students in the chat window and target peer tutor help-giving skills that need improvement (#7 in Figure 2). For example, novice tutors may give instrumental hints like "then subtract" rather than conceptual hints like "to get rid of *qcv,* you need to perform the inverse operation on that side of the equation." When tutors are detected to be giving instrumental hints, the computer uses an assessment of the tutor's help-giving skill to say in the chat window (visible to both students), "Tutor, think about the last help you gave. Why did you say that? Can you explain more?" This utterance is designed to get both students reflecting on the domain concepts behind the next step, and to remind the tutor that help should explain why in addition to what. Prompts are addressed to the peer tutor (e.g., "Tutor, can you explain your partner's mistake?"), and are adaptively selected based on the computer assessment of help-giving skills. For example, as use of the sentence classifiers is an integral component of our ability to assess peer tutor utterances, as well as having potential benefit for the students, when students fail to use the sentence classifiers, they receive prompts suggesting that they should do so (e.g., "The buttons underneath the chat [e.g., "Give Hint"] can help you let your partner know what you're doing"). Students also receive encouragement when they display a particular help-giving skill (e.g., "Good work! Explaining what your partner did wrong can help them not make the same mistake on future problems"). The prompts contain both praise and hedges, such that the computer's voice does not publicly threaten the peer tutor's voice. Only one reflective prompt was given at a time, and parameters were tuned so that students received an average of one prompt for every three peer tutor utterances. There were several different prompts for any given situation, so students rarely received the same prompt twice.

We built a model for good peer tutoring which assessed whether students displayed four help-giving skills: help in response to tutee errors and requests, help that targets tutee misconceptions, help that is conceptual and elaborated, and the use of sentence classifiers to give help. This assessment is the basis for providing students with reflective prompts. Our main focus was supporting peer tutors in giving conceptual elaborated help to benefit their own learning. For example, by encouraging peer tutors to target tutee misconceptions, we hoped to lead them to reflect and elaborate more on the concepts involved in solving the problem. To assess peer tutor performance, the model uses a combination of several inputs. First, it uses *CTA* domain models to access the problem-solving context (e.g., it could tell if tutees had just made an error). Next, it uses student interface actions, including tutor self-classifications of chat actions as prompts, error feedback, hints, or explanations, to determine what the students' intentions were when giving help. Finally, it used Taghelper (Rosé et al., 2008) to automatically determine whether students were giving help, whether the help targeted the next problem step or the previous problem step, and whether the help was conceptual. Based on a combination of these three channels, we used a simple model composed of 15 rules to assess each peer tutor action taken, and used Bayesian knowledge tracing (Corbett & Anderson, 1995) to update a running assessment of peer tutor mastery of the four help-giving skills. For example, if the peer tutor clicked the "give hint" classifier and typed "subtract *x*", the system would classify the utterance as nonconceptual help on the next problem step. The system would then access the *CTA* problem-solving context, and might see that the tutee had recently made an error. The system would consider the peer tutor utterance to be suboptimal collaboration because the peer tutor did not give feedback on the error, and the "target misconceptions" skill assessment would be decreased. If, after any peer tutor action, a skill fell within a predefined threshold for that skill, students were given a reflective prompt targeting that skill. In this particular example, the peer tutor may be told: "Tutor, is there anything your partner doesn't understand right now about the problem?" These prompts are adaptive both with respect to their timing and with respect to their content.

Method

The goals of this study were to investigate the potential beneficial effects of adaptive support on collaboration and learning in a computer-supported peer tutoring setting and to explore two potential mechanisms for these effects. Thus, we compared three conditions:

1) Students received adaptive support and were told it was adaptive (*real adaptive condition*)

2) Students received fixed support and were told it was adaptive (*told adaptive condition*)
3) Students received fixed support and were told it was fixed (*real fixed condition*)

We deployed the three versions of our system in an after-school lab study to examine the influence of the actual and perceived adaptive support on student learning and motivation. Following the *accountability hypothesis* (*H2*), we believed that in the conditions where students perceived support as adaptive (the *real* and *told adaptive conditions*), they would be more motivated to collaborate effectively, and would learn more than the students who perceived the support as random. Following the *relevance hypothesis* (*H1*), we believed that in the condition where support was actually adaptive (only the *real adaptive condition*), students would receive feedback on their help only at moments when they could apply it, and thus would learn more than other students and feel more positively about their tutoring.

Participants

Participants were 130 high-school students (49 males, 81 females) from one high school, ranging from 7th to 12th grade, and currently enrolled in Algebra 1 (46 students), Geometry (49 students), or Algebra 2 (35 students). While the literal equation solving unit was one that all students had completed, the teacher we were working with identified it as a challenging unit for the students, and, in fact, many students did not remember seeing the material before. The study was run at the high school, either immediately after school or on Saturdays. All students were paid 30 dollars for their participation. Students participated in sessions of up to 9 students at a time (*M* group size = 7.41, *SD* = 1.35). Each session was randomly assigned to one of the three conditions, and then within each pair students were randomly assigned to the role of tutee or tutor. Students came with partners that they had chosen, except in the case of 4 students assigned to their partners by the researchers. For ease of scheduling, we sometimes assigned an extra student to a given session (in case somebody did not show up at the assigned time). There were 8 students who worked alone over the course of the session. Thus, a total of 122 students were included in the analysis.

Procedure

This study took place over 3 hours. Students received a brief 5-minute introduction to the study, and then took a 20-minute domain pretest. Next, students spent 20 minutes in a preparation phase, working individually using the *CTA*. Students solved problems involving literal equations where the variable terms were on the same side of the equation (e.g., $ax + bx = cy + dz$; solve for x). Students then spent 30 minutes in the tutoring phase, with one student tutoring another student on problems where the variable terms were on both sides of the equation (e.g., $ax + cy = bx + dz$; solve for x). Students took up to 10 minutes to answer several survey questions on their motivational state, and then spent another 30 minutes in the tutoring phase. At this point, students took a 15-minute break, and then took a 20-minute domain posttest, again consisting of a 10-minute conceptual component and 10-minute procedural component. Students concluded the study by tutoring without support for 25 minutes, and answering demographic questions.

In the tutoring phase, we implemented two between-subjects manipulations where we varied whether students received adaptive support and whether they thought the support was adaptive. As our first manipulation, we varied the adaptivity of the reflective prompts students received. To implement the comparison conditions where students received fixed support, we gave students pseudo-random prompts that ensured that the timing and content of the prompts was not contingent on student actions. Every time students would have received a reflective prompt were they in the adaptive condition, they did not receive a prompt in the fixed condition. However, we ensured that they received a prompt within the next three turns, thus yoking the fixed prompt to the adaptive prompt. We randomly selected the content of the prompt, with one exception: we did not choose content that would have been parallel to the yoked adaptive prompt. Thus, we tried to avoid cases where the fixed support prompts were accidentally relevant (according to our model of adaptivity), making the comparison between the adaptive and fixed support more controlled. For the second manipulation, prior to the tutoring phase, we gave students instructions that told them that the support was either adaptive or fixed. The adaptive instructions were as follows: “The computer will watch you tutor, and give you targeted advice when you need it based on how well you tutor. Both you and your partner will see the help in the chat.” The fixed instructions were as follows: “From time to time, the computer will give you a general tip chosen randomly from advice on good collaboration. Both you and your partner will see the help in the chat.” As students began to use the tutoring system, they were given further instruction on how to use the system, including instructions on how to indicate how they felt about the reflective prompts using ”like” and ”dislike” widgets. To reaffirm the experimental manipulation, students in the *real* and *told adaptive* conditions were told: “We will use that information to improve the computer’s ability to track what you’re doing and give you advice you can use.” Students in the *real fixed* condition were told: “We will use that information to describe which pieces of advice can go into the pool of advice we randomly select from.”

Measures

To assess students' individual *domain learning* we used counterbalanced pretests and posttests, each containing 7 conceptual items and 5 procedural items. Tests were approved by the coordinating classroom teacher, and were administered on paper. We scored answers on these tests by marking whether students were correct or incorrect on each item, and then summing the scores. We further assessed student motivational state in two ways. First, we included several items assessing *perceived collaboration efficacy* relating to how positively students perceived themselves in the interaction (e.g., for the tutor: "I think I was a good tutor"), and how positively they perceived their partner (e.g., for the tutee: "I think my partner learned a lot from being a tutor"). Second, we adapted individual learning orientation questionnaires (Elliot & McGregor, 2001) to assess peer tutor mastery and performance goals for being a good tutor (e.g., "While tutoring, I was worried that I might not learn enough about tutoring", "While tutoring, my goal was to show my partner I was a good tutor"), and tutee mastery and performance goals for helping their partner be a good tutor (e.g., "While being tutored, I wanted my partner to understand how to tutor", "While being tutored, it was important for me that my partner look like a good tutor"). We called this measure *collaboration goal orientation.* For both motivation measures, scores were averaged across all relevant items. Finally, as a manipulation check, we assessed *perceived adaptivity,* with five items asking students how adaptive they thought the system was (e.g., for the tutor: "The computer gave advice at times when it was useful.") and how positively they perceived the system (e.g., for the tutee: "The advice the computer gave improved how well my partner tutored me.").

Results

Domain Learning

We conducted a two-way (condition x role) ANCOVA, controlling for pretest, with posttest as the dependent variable. Pretest score was significantly predictive of posttest score ($F[1,115]=120.43$, $p < 0.001$; see Table 1). There was a significant effect of condition on posttest ($F[2,115] = 4.20$, $p = 0.017$, $eta^2 = 0.068$), indicating that the adaptiveness of support had a positive effect on student posttest performance. A planned comparison of the effects of receiving real adaptive support revealed that it indeed had a significant effect ($F[1,115] = 7.47$, $p = 0.007$), while a planned comparison of the effects of receiving support that students were told was adaptive revealed that this manipulation did not have a significant effect ($F[1,115]=0.393$, $p = 0.532$). These results support the *relevance* (*H1*) but not the *accountability* (*H2*) hypothesis, suggesting that real adaptive support had a more beneficial effect than fixed support, even if students were told that the support was adaptive.

Interestingly, while the effect of role on posttest was not significant ($F[1,115] = 0.751$, $p = 0.338$), there was a significant interaction effect between condition and role ($F[1,115] = 3.334$, $p = 0.039$, $eta^2 = 0.055$). Applying the planned comparisons based on *H1* and *H2* to the interaction effect revealed that while the effects of real adaptivity did not differ across the two roles ($F[1,115] = 2.660$, $p = 0.106$), told adaptivity had differential effects on peer tutors and tutees ($F[1,115] = 6.561$, $p = 0.012$). Inspecting student learning across role and condition (see Table 1) revealed that peer tutors benefit more from the told adaptive condition than the real fixed condition, but tutees benefit more from the real fixed condition than the told adaptive condition. The perception of adaptivity may have an effect on peer tutor feelings of accountability and thus may positively influence their learning. However, the perception that the tutoring advice is relevant when it is not may impede the tutoring abilities of the peer tutor and thus may lead to less tutee learning than in the real fixed condition.

Table 1. Pretest and posttest scores for the tutee and tutor. Scores represent percent correct.

	Real Fixed		Told Adaptive		Real Adaptive	
	Tutor	Tutee	Tutor	Tutee	Tutor	Tutee
Pretest Score	0.29 (0.15)	0.23 (0.16)	0.24 (0.12)	0.28 (0.18)	0.27 (0.16)	0.28 (0.15)
Posttest Score	0.28 (0.18)	0.33 (0.21)	0.27 (0.16)	0.29 (0.14)	0.39 (0.17)	0.36 (0.21)

Tutoring Efficacy and Goal Orientation

We then investigated the motivational effects of the manipulation. We assessed how positively students felt about their and their partner's tutoring abilities in the *perceived collaboration efficacy* measure, using a two-way (condition x role) ANOVA (see Table 2, row 1). We found that condition significantly affected student positive feelings of perceived collaboration efficacy ($F[2,102] = 5.58$, $p = 0.005$), as did role ($F[1,102] = 5.10$, $p = 0.026$). There was no significant interaction of condition and role ($F[2,102] = 0.542$, $p = 0.583$). We then looked at the effects of condition on tutoring mastery and performance orientation using the *collaboration goal orientation* measure (see Table 2, rows 2 and 3). Condition did not have a significant effect on either variable (mastery orientation: $F[2,99] = 0.501$, $p = 0.607$; performance orientation: $F[2,99] = 0.679$; $p = 0.510$).

Table 2. Motivational effects and manipulation check. Standard deviations are presented in parentheses. Scores are on a 7-point Likert scale, with 7 being the most positive response.

	Real Fixed		Told Adaptive		Real Adaptive	
	Tutor	Tutee	Tutor	Tutee	Tutor	Tutee
Collaboration efficacy	4.53 (1.28)	5.35 (1.37)	4.68 (1.86)	4.90 (1.39)	5.43 (1.03)	6.14 (0.67)
Mastery orientation	4.93 (1.10)	5.15 (1.24)	4.94 (1.05)	5.10 (1.17)	5.28 (1.10)	5.46 (1.52)
Performance orientation	4.77 (1.17)	5.08 (1.01)	4.78 (1.25)	4.72 (1.59)	4.85 (1.05)	4.82 (1.25)
Perceived adaptivity	4.75 (1.60)	4.79 (1.56)	5.06 (1.05)	4.54 (1.30)	4.84 (1.30)	5.23 (1.25)

Perceived Adaptivity

As a manipulation check, we evaluated how adaptive and effective students thought the system was (*perceived adaptivity*; see Table 2, row 4). In a two-way (condition x role) ANOVA, there were no significant effects of condition on perceived adaptivity ($F[2, 96] = 1.046$, $p = 0.355$), no significant effects of role ($F[1,96] = 0.00$, $p = 0.992$), and no interaction ($F[2,96] = 1.741$, $p = 0.181$).

Discussion and Conclusions

In this paper, we described *APTA*, a system for adaptively supporting peer tutoring, and conducted a study where we compared a condition employing *APTA* to two conditions employing a fixed support system. The results suggested that compared to fixed support, adaptive support improved the domain learning of peer tutors and tutees. This result adds to the small list of studies demonstrating the effectiveness of adaptive collaborative support at improving learning (e.g., Kumar et al., 2007). We also found that students who received adaptive support thought they were better collaborators than their fixed support peers. As there is a positive link between efficacy and motivation, this finding suggests that adaptive reflective prompts may help overcome motivational drawbacks of fixed support systems (e.g., Dillenbourg, 2002).

One of the central questions of this research agenda is: how adaptive does support need to be? The effectiveness of the real adaptive support compared to the told adaptive support provided evidence for the *relevance hypothesis* (*H1*; the top path in Figure 1). As the fixed support conditions received approximately the same collaborative support content as the adaptive support condition, we can conclude that it was the adaptive presentation of the content at appropriate moments that enhanced student learning and motivation. We also tested whether by simply telling students that support was adaptive, even when it was not, students might learn more from the collaboration (*accountability hypothesis*; *H2*; the bottom path in Figure 1). This hypothesis was not confirmed. Peer tutors may have received some benefit from the perception of adaptivity, but tutees performed worst in this condition. Moreover, the adaptivity of support had a significant effect on collaboration efficacy but not goal orientation, further supporting the *relevance hypothesis* over the *accountability hypothesis.* Despite these results, we found no differences between conditions in student reports of how adaptive they found the system. It is interesting that although students in the real adaptive condition did not appear, on the survey measure, to perceive the system as more adaptive, they still received beneficial effects of adaptivity.

This study tried to identify guidelines for supporting collaborative learning using controlled experimentation in a school context, and further focused on uncovering the underlying mechanism by manipulating particular aspects of adaptive support. Theoretical progress in understanding the potential of adaptive support for collaborative learning will be enhanced by further investigations of alternative mechanisms for how, when, and why particular forms of adaptive support are effective. In general, the positive learning and motivational results relating to real adaptive support encourage the continuation of research into adaptive support for collaboration, suggesting that the time and effort necessary to develop this support is worthwhile.

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