Beyond Explicit Feedback: New Directions in Adaptive Collaborative Learning Support

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Abstract: Adaptive collaborative learning support (ACLS) may be better than fixed forms of support at increasing learning from collaboration. While much existing adaptive assistance has focused on providing explicit feedback directly to the relevant student, we propose a two-dimensional design space which explores alternative methods of adaptive assistance that are implicit, indirect, or both. We investigated the viability of these ideas using data collected in a classroom evaluation of an ACLS system for peer tutoring which incorporated the design ideas in a manner that provided cognitive support to peer tutors. In this paper, we discuss how students interacted with the different forms of feedback, and propose a second iteration of the assistance that involves collaborative support in addition to domain support.

Introduction

Collaborative activities have been shown to be a good way of improving student learning, but effects are not found when students do not interact in positive ways (Lou, Abrami, & d'Appolonia, 2001). Thus, researchers implement collaboration scripts, which support student interaction using clearly defined roles and activities (e.g., O'Donnel & Dansereau, 1992). Most script support for collaboration that has been implemented so far has been *fixed*, and do not change based on student behavior. *Adaptive* support, which would provide assistance to students when and where they need it, might improve upon or complement many fixed forms of support (Rummel & Weinberger, 2008), and has indeed been shown to have a more positive effect on student learning (Kumar, Rosé, Wang, Joshi, & Robinson, 2007). However, few full systems have been implemented or had their learning effects evaluated (see Soller, Jermann, Muehlenbrock, & Martinez, 2005, for a review).

One potential reason for the slow progress in the field is that much adaptive collaborative learning support (ACLS) follows an individual learning model established in intelligent tutoring technology (see Van Lehn, 2006). Student collaboration is compared to a model of ideal collaboration, and discrepancies are addressed by providing *explicit* feedback on the next course of action *directly* to the student who is collaborating suboptimally (Soller et al., 2005). For example, COLER (Constantino-Gonzales, Suthers, & de los Santos, 2003) provides explicit advice to nonparticipating students such as, "George, participation is a learning opportunity. I suggest that you leverage it. Come on, participate! :)". Similarly, COLLECT-UML (Baghaei & Mitrovic, 2007) provides individual feedback on a UML modeling task such as "Some relationship types (associations) in your individual solution are missing from the group diagram. You may wish to share your work by adding those association(s)/discuss it with other members." This type of feedback might not be the most effective way of supporting collaborating students, as it favors cognitive processes without attending to social interactions, potentially distracting or overloading students. In fact, Kumar and colleagues (2007) found that students tended to ignore adaptive prompts while collaborating. Thus, it might be productive to explore the effects of other forms of feedback on student interaction and learning.

In this paper, we outline a design space for adaptive feedback involving two dimensions: whether the action that students should take is explicitly described in the feedback or implicitly arises as a result of the support (*explicit* or *implicit*), and whether it is presented directly to the person it targets or presented indirectly to another party or through a change in the learning environment (*direct* or *indirect*; see Figure 1). So far, most ACLS systems have been located in the lower right quadrant of Figure 1. We intend to further explore the possibilities for adaptive support by investigating a design idea in each of the other three quadrants.

1. *Adaptive Opportunities* modifies the learning environment in order to create learning opportunities for students. For example, problems could be adaptively assigned to students based on their previous interactions. Here, the change to the learning path is implicit, and feedback is presented indirectly.
2. *Peer-Mediated Feedback* encourages students to better self-regulate their learning. For example, if one student is not explaining a step clearly, we can prompt their partner to ask, "What do you mean by that?" rather than telling the first student to expand their explanation. This approach is indirect, as it is not presented directly to the relevant student, but explicit because the next course of action is clear.
3. *Adaptive Resources* provides resources to students at moments when they need them. For example, a video related to a given concept could be presented when a student may be thinking of applying the concept, and additional materials surrounding the video could incorporate specific information about the current problem or collaborating students. Here, the presentation of the resources is directly to the relevant student, but the course of action is implicit.

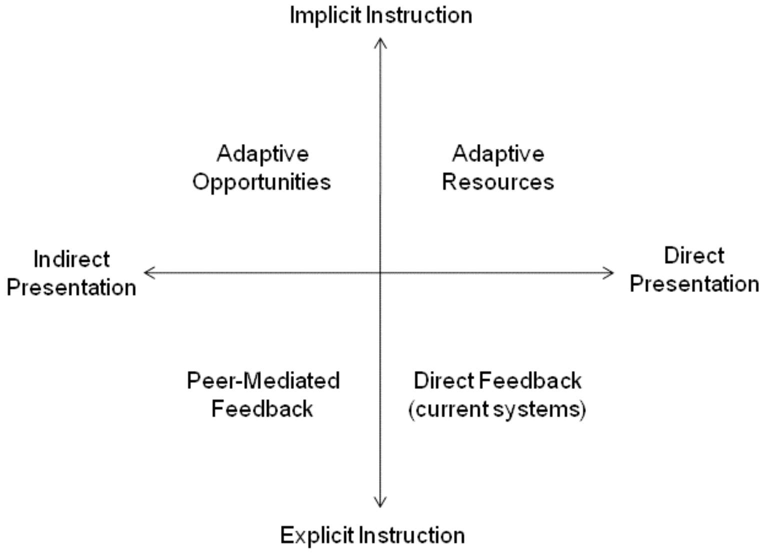

Figure 1. Design space for adaptive collaborative learning support.

We explore the viability of each idea using data collected from an existing adaptive collaborative learning system for peer tutoring, APTA (Adaptive Peer Tutor Assistance). APTA is an extension to the Cognitive Tutor Algebra, a successful intelligent tutoring system for individual learning in Algebra (Koedinger, Anderson, Hadley, & Mark, 1997). Using APTA, students take turns tutoring each other; the *peer tutee* solves the problem, and the *peer tutor* marks steps right or wrong, and gives the tutee hints and feedback in a chat window. In turn, the tutee can ask for help and self-explain. The system provides fixed domain support (the peer tutor can view a worked-out problem solution) and adaptive domain support (if the peer tutor marks something right and it is actually wrong, the system will intervene with a prompt to collaborate and a cognitive hint). We evaluated APTA in a classroom study that took place over the course of 2 weeks with 51 collaborating students (Walker, Rummel, & Koedinger, 2008), and the examples and observations addressed in this paper were drawn from that study. Each design idea has been realized to differing extents in the domain help provided by the system, enabling us to learn about how collaborating students might respond to the design ideas. We further discuss the implications of the initial results for further development of the designs.

Designs for Collaboration Support in the Context of APTA

Adaptive Opportunities

The current implementation of this design idea within the context of APTA is somewhat reflected in the adaptive instructional support delivered by the tutoring system, which attempts to set up opportunities where both parties reflect on and repair their misconceptions. To accomplish this goal, the system compares each peer tutor assessment of tutee actions to the cognitive tutor assessment, and makes peer tutors aware of discrepancies that arise. Table 1 illustrates an example from our study where the tutor marked a problem step correct, but then was presented with information from the intelligent system which demonstrated that the step was in fact incorrect. The peer tutor determined how to repair the error and take the next correct step. Although the outcome of his reasoning was communicated to the tutee, the process itself was not made transparent, potentially explaining why the delayed gain of the tutor was 0.375, while the tutee showed a delayed gain of 0.125. In general, tutors appeared to benefit even from simply viewing tutee errors.

This design idea might more usefully be applied in creating the opportunity for errors to be committed through the adaptive selection of problems that lead to errors. There were two obstacles preventing errors from being committed by the tutee. First, many problems were too easy for tutees. Second, some peer tutors were overzealous in helping tutees, such that tutees had no chance to commit errors. We would see a pattern where a given tutor would give the tutee an instruction like "factor q", the tutee would execute the action, and the tutor would immediately give the next instruction like "divide by a + b". Therefore, our next step in implementing this design idea is to create the conditions where errors are made. As in the individual version of the CTA, we plan to assess the skills that tutees have mastered, and adaptively select problems where tutees are likely to make errors that both parties can benefit from. Simultaneously, we will assess the peer tutor tendency to provide unsolicited help before a step has been attempted, and, if it is high, select problems for the tutee that the peer tutor has not yet mastered. Hopefully, if the peer tutor is struggling with the concepts in the problem, he or she will be less able to simply walk the tutee through the problem, and more joint knowledge construction will occur. This intervention is potentially advantageous because of its subtlety; students are unlikely to notice the deliberateness of it, but it has the potential to increase the opportunity for tutees to make errors and therefore the potential for learning. Adaptively selecting problems to improve learning conditions is an example of guidance with an indirect presentation, as it is not directly delivered to the student, and implicit instruction, as it does not make the next interaction steps clear to students.

Table 1. Learning opportunity created by tutee error while solving the equation "3q-xq = x."

Step Description	Analysis
Tutee selects "factor q", but types "3q = x".	The tutee knows what to do, but is not sure how to complete the step.
Peer tutor approves the calculation, and receives error feedback from the cognitive tutor.	The peer tutor initially thinks the step is correct, but is made aware from the system that it is an error, creating a learning opportunity.
The peer tutor tells the tutee "undo that step", but the tutee proceeds by dividing by 3. The tutee clicks the done button, but the peer tutor disagrees.	The peer tutor understands that the tutee has not solved the problem.
The students have the following exchange: Peer tutor: undo it Tutee: why? U marked it right? Peer tutor: the step is right but it said you made a typing error when you factored The dialog continues until the tutee confirms which step to undo.	The peer tutor identifies the error for the tutee in an unelaborated way.
The tutee undoes the step, and the tutor explicitly tells the tutee what to do, after asking for a hint: Now factor out q. It should be q(3 – x) + x. q(3 – x) = x, sorry	The peer tutor then tells the tutee how to complete the step, correcting his own error.

Peer-Mediated Feedback

The current implementation of peer-mediated help in our system lies in the way assistance was presented, where error feedback and hints on *tutee* problem-solving actions were presented to the peer *tutor*. We hoped that the peer tutor would elaborate on the help and adapt it to the tutee's needs, improving the learning of the tutee. Below, Table 2 contains an example drawn from a different pair than Table 1. The peer tutor is told that they are not actually done with the current problem, and then more successfully communicates hint feedback to the tutee than the peer tutor from the previous example. In this pair, the tutee had a gain score of 0.375 on the delayed posttest. Here, the tutee benefitted from committing an error and engaging in a dialog with the tutor.

Table 2. Example of peer-mediated feedback. Students are solving for *t* in the equation: t = (-bh+mn)/(-v-r). They need to simplify the equation.

Step Description	Analysis
Tutee selects the done button. Peer tutor incorrectly agrees, and receives feedback from the system.	Both students are surprised to hear that they are not done.
The tutee says, "do u kno wat i should do". The tutor looks at the problem solution.	The tutee asks for a hint, and the tutor consults the worked example to help her.
Students have the following dialog: Tutor: look at the neg sign on the denominator Tutee: but wat do i do to get rid of the negative? Tutor: the neg has to disappear u ll find it in trans Tutee: will u please just tell me already? Tutor: i don't remember what it's called The dialog continues until the tutor realizes that he does not actually know the specific next step.	The tutor begins to give elaborated help, but lacks the knowledge to fully identify and explain the step. The tutor is unsuccessful at helping the tutee.
The peer tutor asks for a hint from the cognitive tutor. She communicates the help, saying "use common factor". The tutee simplifies fractions and then promptly undoes it. The tutor says, "-1" , and the tutee factors -1. Finally, the tutor says, "now simplify." The tutee simplifies and completes the problem.	The peer tutor uses a hint to provide a series of procedural instructions to the tutee. The tutee successfully completes the problem.

This example illustrates an additional place for implementing peer-mediated feedback. One difference between the examples in Table 1 and Table 2 is that the peer tutor in Table 2 attempted to explain the error, which was less the case in Table 1. Often, even when peer tutors transferred the system feedback they received to the tutees, they did not elaborate sufficiently on the feedback. Therefore, we propose to use "reverse" mediated feedback to the tutee in order to encourage tutors to produce better explanations. For problem steps where tutees receive help from the tutor, and it is likely that they do not understand the concepts involved with the help, we plan to deliver indirect explicit feedback to the peer tutee such as: "Wait -- do you understand why you should subtract *x*? If not, ask your partner why." This approach is in contrast to a direct and explicit feedback approach, where the prompt would generally be given to the peer tutor: "Why don't you tell your partner why they should subtract *x*." In this proposed "reverse" mediated feedback, it is not so clear that blocking other tutee actions (e.g., problem-solving actions) as they receive this feedback is the best direction, as it takes away some tutee control over their environment. How to balance student control with partner confusion is still an open question. Nevertheless, we envision that this mediated feedback will promote better self-regulation of the collaborative learning and potentially trigger a deeper interaction.

Adaptive Resources

Another attempt to help peer tutors provide good advice to tutees was by providing them with a worked-out solution to the problem in the interface. As an implementation of the *Adaptive Resources* design idea, this approach is limited, because the resource (the problem solution) did not change during problem-solving. However, looking at how students used this fixed resource might give us better insight into how tutors might benefit from an adaptive resource. Students appeared to use the problem answers in two ways: to check the work of their partner and to figure out the next problem step. In fact, the problem solution was consulted frequently in the course of regular problem-solving so that the peer tutor was always prepared to give help. Thus, we see an opportunity here to adaptively present resources in order to encourage deeper conceptual interaction amongst the students. In the process of comparing the tutee actions to the problem answers, some tutors were able to generate help that contained conceptual information, suggesting that they were engaging in beneficial knowledge-building processes. Table 3 is an example of a conceptual exchange observed between students, where the peer tutor involved had a gain score of .625 on the delayed test. Although this exchange is the type of interaction we were hoping to see, this kind of conceptual help was rare among students.

Table 3. Conceptual interaction about problem ay + by + m = n

Step Description	Analysis
The tutee factors *y*. The tutor checks the problem answers (which say to subtract *m* from both sides). The tutor marks the problem step wrong, and the tutee undoes the step.	The tutor (incorrectly) flags the tutee because her solution doesn't match the problem-solving action
The students have the following dialogue: Tutor: ok um what variable is by itsself Tutor: that is the one you need to get on the other side Tutee: right now just "n" but i have to get "y" by itself Tutor: look at the equation ay+by+m ...wat 1 is bby itself Tutee: m	The tutor conceptually explains the first step as she sees it.
The tutee adds *m*. The tutor gives a hint: Tutor: look at the sign b4 n	The tutee makes a conceptual error, and the tutor immediately moves to correct it.
The tutee combines like terms. The tutor checks the problem answers and flags the step. The tutee undoes both steps.	The tutor uses the fixed resource to verify her thinking, then marks the step wrong.
Tutor: look at the sign b4 the m is it a plus or a minus Tutee: it a plus so i would wnt to minus it from the rest of the problem	The tutor continues giving the conceptual hint. The tutee self-explains her reasoning.

We intend to explore two types of adaptivity in delivering resources to students: Changing the content of the resources based on the current problem state, and changing the content of the resources based on an assessment of student knowledge. There are several different types of resources we can provide to peer tutors other than a worked out problem example, arranged in order from most general to most specific:

R1. Conceptual description of how to solve the problem rather than the problem steps
R2. Example of a similar problem, but using numbers in place of letters representing constant terms
R3. An annotated worked-example with conceptual explanations for each step

Different levels of help might be appropriate at different times in the problem: The earlier resources might be better for tutees who have mastered the skills necessary to solve the problem or have not made many attempts at the problem step, while the later resources might be better for students who have made several incorrect attempts or are not expected to have the skills required for the problem. Additionally, the content of the resources themselves could be adapted based on information about the current problem-state, skill mastery, or student interaction. For example, R2 could also display the errors made by the tutee on the problem using numbers in place of letters, or R3 could derive the conceptual explanations using language that students have used previously. Making the resources adaptive means that we can provide peer tutors with a wide variety of different resources over the course of the activity without overloading them, and we can tailor the presentation of each resource to the particular problem situation and to the abilities of the tutee.

Discussion

In this paper, we have outlined a design space for the delivery of adaptive feedback to collaborating students, focusing on two dimensions: the explicitness of the feedback content, and the directness of the feedback presentation. The three ideas that we have generated, each falling into a quadrant of the design space, are not incompatible with direct feedback, nor are they incompatible with each other. It is likely that each idea is best applied in particular contexts, and multiple feedback types should be integrated within a single system. In APTA, it makes sense to use adaptive opportunities to create an amount of errors sufficient for the peer tutor to benefit from the interaction, mediated feedback to encourage tutors to generate explanations rather than instructions when tutees make errors, and then adaptive resources to help peer tutors put conceptual elements into their explanations. In the cases where one feedback type doesn't work, a second feedback type might be more appropriate; for example, if mediated feedback isn't being communicated, it would seem natural to switch to direct feedback. Determining when and how to apply each kind of feedback is still an open research question, with the ultimate goal of optimally facilitating computer-supported collaborative learning interaction.

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