

Facilitating teacher to student communication using Classroom Learning Partner

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1. Introduction

In today's world, great hopes are associated with the possible use of educational technology. Unfortunately, many technological innovations are introduced into classrooms without any understanding of how they will benefit the students and the teacher and what their potential drawbacks are. Worse yet, often when technology is introduced, it replaces the traditional student-teacher interaction, instead of being used as an aid in the classroom. Meanwhile, many researchers believe that effective communication between the teacher and the students is crucial for education to be successful (Black and William, 1998; Bransford et al., 2000). The goal in creating educational technology should therefore be to facilitate student-teacher communication, not to replace it.

The research described in this report contributes to the communication protocol of a network of wireless computer tablets called Classroom Learning Partner, which is used in an educational setting much like the one described in the following scenario:

Julia enters the classroom and approaches her seat. She takes out her tablet computer, turns it on, and connects to the classroom via a wireless network. The tablet displays the teacher's lesson for the day. After reviewing the previous day's lesson on fractions, the teacher asks the students to complete the exercises, which they can see on their computer.

Julia has had no problem understanding the material. She uses a tablet pen to write down the answers as well as to create colorful graphs and sketches and submits her answers to the teacher who can now see Julia's submission on her own computer. Meanwhile, Julia's friend Katie is having trouble with one of the exercises. Katie is very shy and afraid to raise her hand and ask for help. She writes "I need help" as the answer and submits it. The teacher sees Katie's submission, and approaches her to explain the concept again. She also creates a picture that should help visualize the problem and sends it to Katie. Katie then submits an answer, the teacher reviews it, writes "Good job!" on it and sends it back to Katie.

In section 2 of this report, I give an overview of the state of the system before my work on it began. I describe the system's components and give an overview of its communication modes and protocols. Next, in section 3, I present my own contributions to Classroom Learning Partner. I explain the need that arose for two new modes of communication and give details on the design and implementation of both of them. In section 4, I describe the applications of the features that I have introduced and give examples of how these features were used by a fourth grade teacher during classroom trials. Finally, in section 5, I propose possible additions to the communication protocol of the system and give an outline of how such additions could be implemented.

2. Previous work

Classroom Learning Partner is a system designed and used to improve classroom interactions between teachers and students. It is based on a system called Classroom Presenter (Anderson 2004, 2007) which enables students to wirelessly submit answers to in-class exercises. Initially, Classroom Learning Partner was designed for undergraduate college courses (Koile 2006, 2007). However, through a project entitled *Ink 12: Interactive Ink*

Inscriptions in K-12, Dr. Kimberle Koile from MIT has been adapting the system to make it suitable for elementary and middle school math and science classes (Koile 2008).

2.1 System components

Classroom Learning Partner (CLP) is used in classrooms on a wireless network of tablets with three distinct functions. All the computers are physically the same, but run the Classroom Learning Partner software in different modes. The teacher uses an instructor tablet and each of the students has their own student tablet. In addition, there is a “public” tablet, which is connected to a projector. The contents of the screen of the public tablet are displayed on the projector for both the teacher and the students to see. Figure 1 illustrates the functionality of the public tablet.

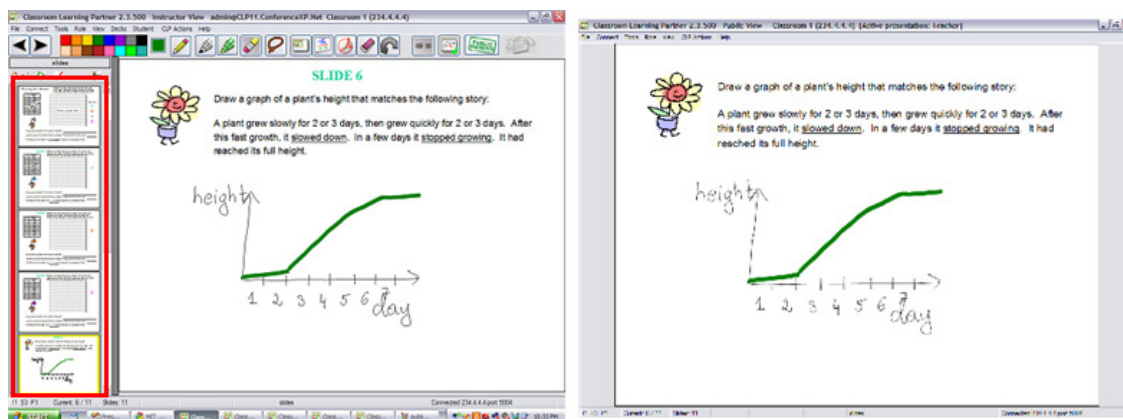


Figure 1. Functionality of the public tablet. The left image illustrates the teacher’s tablet. The filmstrip on the left contains all the slides. The currently selected slide is displayed in the main panel. The right image illustrates the public tablet. The public tablet displays the selected slide of the teacher’s tablet, but does not contain a film strip. As a consequence, only the selected slide, not the film strip, is displayed on the projector.

The main purpose of Classroom Learning Partner is to allow students to solve in-class exercises using a tablet pen and submit their answers to the teacher. The exercises are represented on all the tablets as a deck of slides, with each slide containing one exercise. Students can create digital ink inscriptions on their slides using their tablet pen to simulate

pens and markers of different colors and submit their answers to the teacher. The teacher then can look at the student submissions and write on them while discussing the correct answers with the students. The submissions, as well as the written comments, are displayed on the projector in real-time. Although the teacher knows who sent which submission, the answers are displayed anonymously on the public screen. Figures 2 and 3 shows the user interface of the student and the instructor mode of CLP respectively. The colored boxes are added for emphasis; they are not part of the CLP user interface.

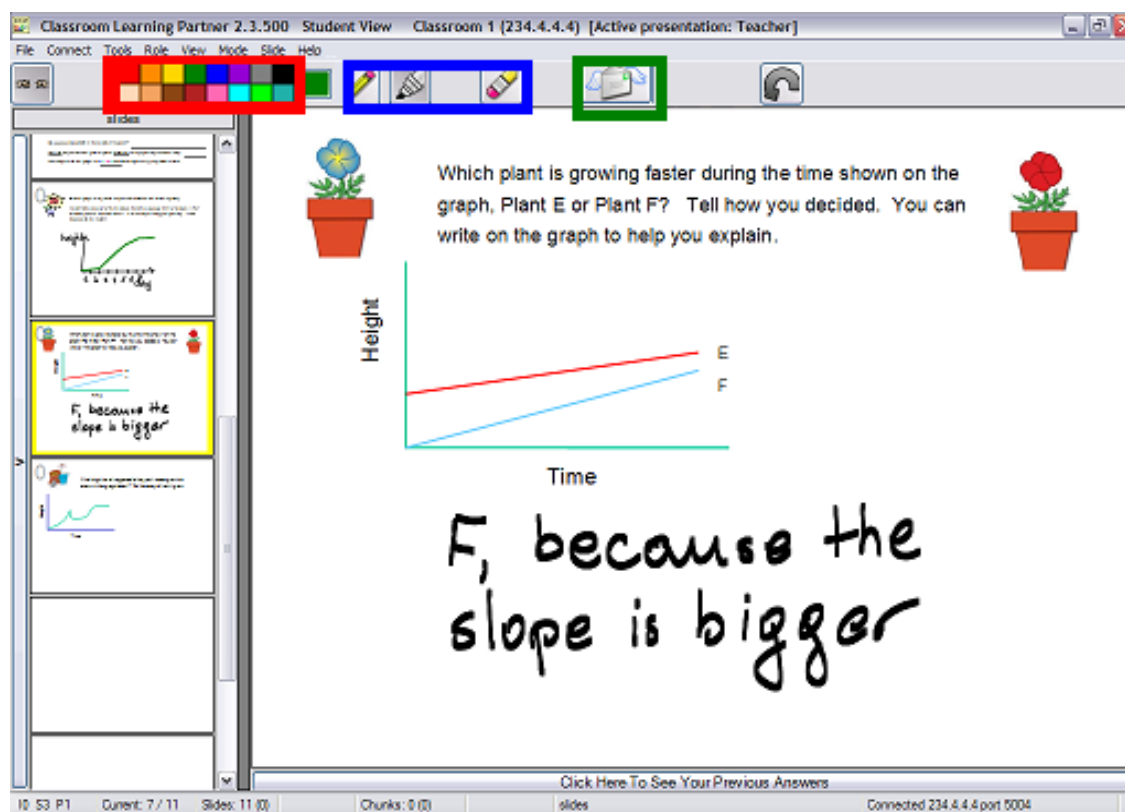


Figure 2. User interface of the student version of CLP. In the red box: pen and marker colors available to the student. In the blue box: pen, marker, and eraser tools. In the green box: button allowing to send a submission to the teacher.

2.2 Communication modes

Classroom Learning Partner supports two forms of communication:

- From a single student to the teacher
- From the teacher to the projector and all the student tablets.

The communication from the student to the teacher is straightforward. Students simply write their answers and send the digital ink to the teacher by clicking on a submission button (see Figure 2). The communication from the teacher to the projector and the student tablets is more complicated as it allows multiple types of messages to be sent and consists of multiple modes.

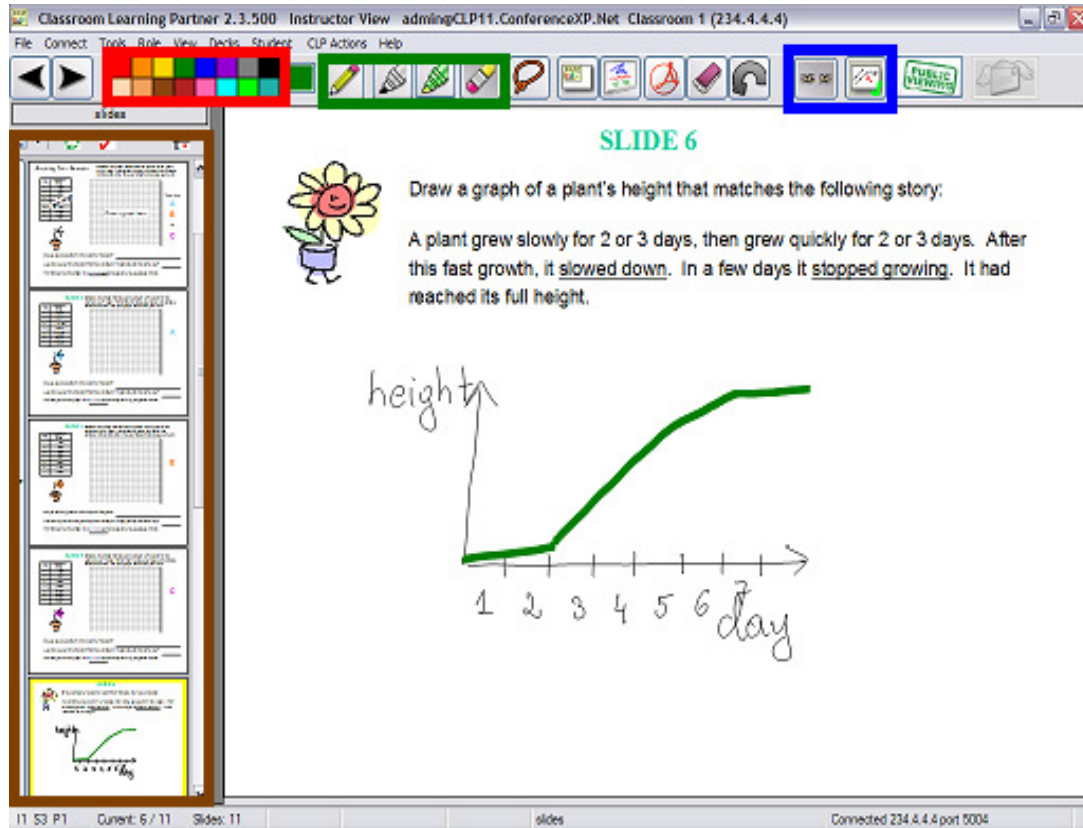


Figure 3. User interface of the teacher version of CLP. In the red box: pen and marker colors available to the teacher. In the green box: pen, marker, highlighter and eraser tools. In the blue box: buttons for linking/unlinking students (see below for definition) and toggling student receipt of instructor ink on and off. In the brown box: film strip with slides. Student submissions will appear there if the teacher selects a slide deck with student submissions.

There are two main types of messaging that go from the teacher to the projector: navigation and inscription. As the teacher looks through her own slides and the student submission slides, her tablet broadcasts a message whenever the slide she is looking at has changed. The public tablet receives that message and switches to the new slide, which causes

that slide to display on the projector. Similarly, if a teacher writes an inscription on a slide, or erases an inscription, a message is also sent to the public tablet, which copies the inscriptions or erases them. The teacher's writing is then visible on the projector.

The communication between the teacher and the students is similar. Both navigation and inscription messages are being sent to all student tablets. The only difference is that student submission slides are not displayed on the student computers. If a teacher is looking at a student's submission, no change is made on the students' screens. There are, however, different modes of communication which can turn the receiving of navigation and inscription messages on or off on the student's version of CLP:

1. *Linking*. If the teacher wants to allow the students to go through slides at their own pace, she can click a button to "unlink" them. In this case, the navigation messages will not be received by students and the slides they look at will not change as the teacher looks through her own slides. The public computer, however, will still follow the teacher's navigation.
2. *Toggling ink*. The students are often bothered by the fact that a teacher can write on their slides. The teacher can therefore choose to toggle off students' receipt of her ink. If the ink is off, only the public computer will receive and display the teacher's ink.

The communication modes can be combined in an arbitrary way. It is, for instance, possible to toggle off student receipt of teacher ink, but keep the students linked.

2.3 Communication protocol

The types and modes of communication are made possible by CLP's communication protocol which decides which tablets receive which messages. There are many types of messages sent, the most important of which are:

- *StudentSubmissionMessage* – contains the students’ digital ink submission
- *RTStroke* – contains the ink written by the teacher on her current slide
- *RTStrokeErased* – contains information about which ink stroke has been erased by the teacher
- *CPPageUpdate* – contains the index of the slide which the teacher is currently looking at

In general, all messages are broadcast via a multicast protocol to all computers and there are many ways to determine which computers should actually accept which messages. The main way to do so is by using a *senderID* field, which is attached to the message and indicates which computer sent the message. Each type of CLP software—student, teacher and public—have their own way of determining which messages to receive:

- The students only accept the message if the *senderID* is the same as the *presenterID*, that is the ID of the teacher computer. This means that no student tablet will, for instance, receive a submission from another student.
- The teacher computer accepts all messages except for the ones sent by itself. This means it receives all the messages with *senderID* not equal to *presenterID*.
- The public computer never sends any messages. It accepts messages from all sources, both the teacher and the students.

The linking and toggling instructor ink modes are handled separately by the communication protocol. To toggle student receipt of ink on or off, the teacher tablet sends a special kind of message: *CPEnableInstructorInk* or *CPDisableInstructorInk*. Upon receipt of such a message, a flag called *allowInstructorInk* is set to *true* or *false* respectively. Consequently, the student tablets only accept an *RTStroke* message if *allowInstructorInk* is set

to *true*, that is if student receipt of ink has been turned on. This protocol is illustrated in Figure 4.

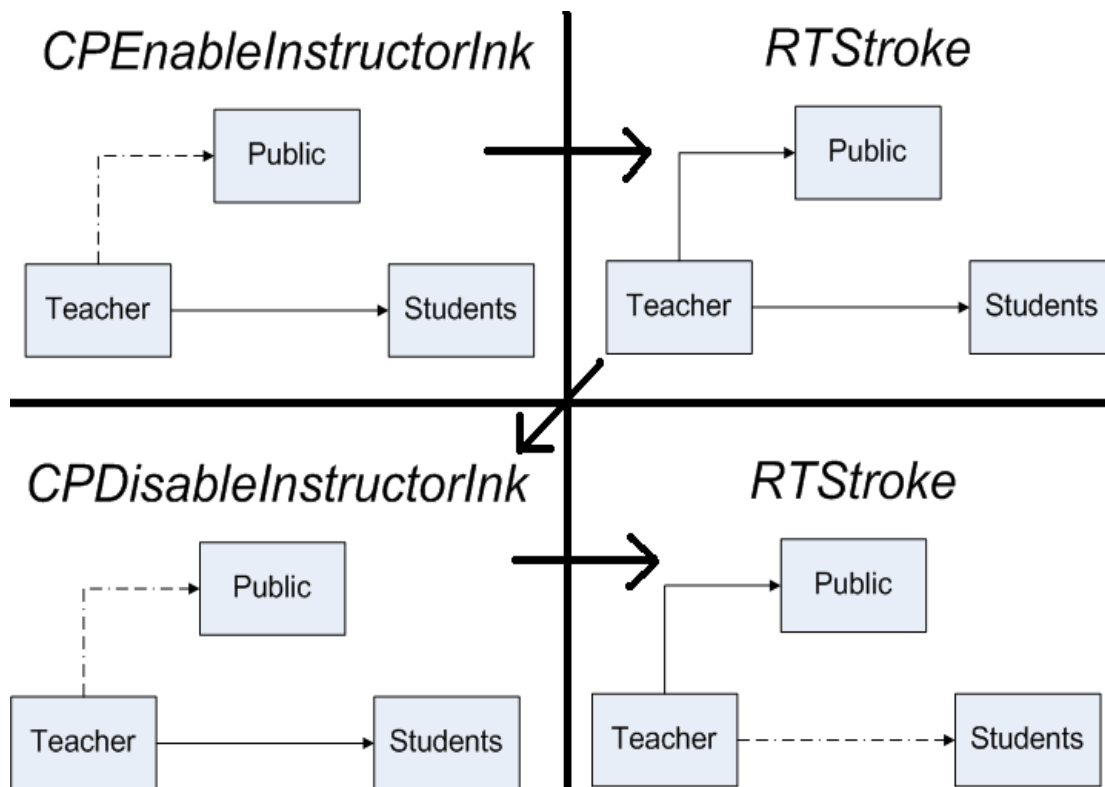


Figure 4. Protocol for toggling student receipt of instructor ink on and off. Solid arrow lines indicate that the message was received and accepted. Dashed arrow lines indicate that the message was received but rejected and not processed. Notice that only the student tablets respond to a mode change (*CPEnableInstructorInk* or *CPDisableInstructorInk*) and that student tablets only respond to new ink sent (*RTStroke*) if they have not had this option disabled by a *CPDisableInstructorInk* message.

3. Contributions

Although the basic functionality of the communication protocol of Classroom Learning Partner had made student-teacher interactions possible, there was still room for improvement before I began work on the project. First of all, even though the students could send personal messages to the teacher, the teacher could not send personal messages to

selected students. Depending on the settings on the instructor's tablet, a message would be received by either all of the students or none of them. In addition, all the instructor's actions were communicated to the public tablet and therefore displayed on the projector. There was, for instance, no way for the teacher to look at the students' submissions without having them display on the projector and be visible to everyone. In this section, I describe my design and implementation of new CLP features which allow the teacher to send private messages to individual students and to navigate slides and write on them without her actions being displayed on the public projector.

3.1 Private teacher-to-student messaging

3.1.1 Purpose and implementation

The main purpose of introducing private teacher-to-student messaging was to allow the teacher to send personalized comments and hints to students, thereby improving the quality of the communication between the two parties. In addition, thanks to new user interface features implemented by Brandon Pung, the students now are able to look at the history of their submissions to each exercise, as well as at the comments that the teacher sent them. All the teacher needs to do is write a personal message on a student submission slide and click a button that sends the message to that student.

Two stages had to be implemented in order to make the teacher message reach the correct student. First, the message itself had to be created. To achieve that, I defined a new class called *TeacherAnswerMessage*, the design of which was based on the design of the *StudentSubmissionMessage*. The new class contains the following fields:

- *slideOverlay* – the actual ink sent by the teacher. Since the student has the copy of the original slide, this ink will be laid on top of the slide to create a full slide

with the teacher's comments while making the amount of information transmitted smaller

- *deckIndex* – the index of the deck on the student machine that the original slide came from
- *slideIndex* – the index of the slide in its deck on the student machine; both the index fields allow the student machine to match the teacher message to the slide it concerns and save the ink in the correct slide's submission history
- *friendlyName* – the name of the student which the message is intended for
- *presenterID* – the ID of the teacher's computer
- *submissionID* – a number distinguishing the submission to which the teacher replies from other submissions that the student might have sent to the same exercise.

After creating the message, I had to make sure that only the intended recipient will accept it. The *friendlyName* field enabled the implementation of this restriction. Upon receiving a *TeacherAnswerMessage*, the student's tablet checks that the *friendlyName* contained in the message matches its own *friendlyName*—a name selected by the student upon logging into the system. If it does match, the message will be accepted and processed. If not, the message will be rejected. The functionality of the private communication protocol is illustrated in Figure 5.

3.1.2 Design trade-offs

The use of a *friendlyName*, as opposed to a *receiverID*, which would have made the system more consistent with the *senderID* already in use, was an important design decision when creating the *TeacherAnswerMessage*. The reasoning behind this decision was to make failure recovery possible. Specifically, if a student's tablet fails for some reason and a student

needs to use a new machine, the *ID* of the machine will change. The student's *friendlyName*, however, chosen upon logging into the system, will remain unchanged. Consequently, the student will be able to receive teacher comments on answers he or she submitted before the computer malfunctioned.

The second design decision I made prevents the student from erasing the comments sent by the teacher. The components of the system already in place made this goal easier to achieve. Each slide contains an associated *Overlay*, which stores the ink written on it. There are two types of ink: *userScribble* and *otherScribble*, only the first of which can be erased. To make it impossible for the student to erase teacher comments, I made a copy of all the teacher strokes and saved them in the *otherScribble* before putting them in the *slideOverlay* field of *TeacherAnswerMessage* to be sent.

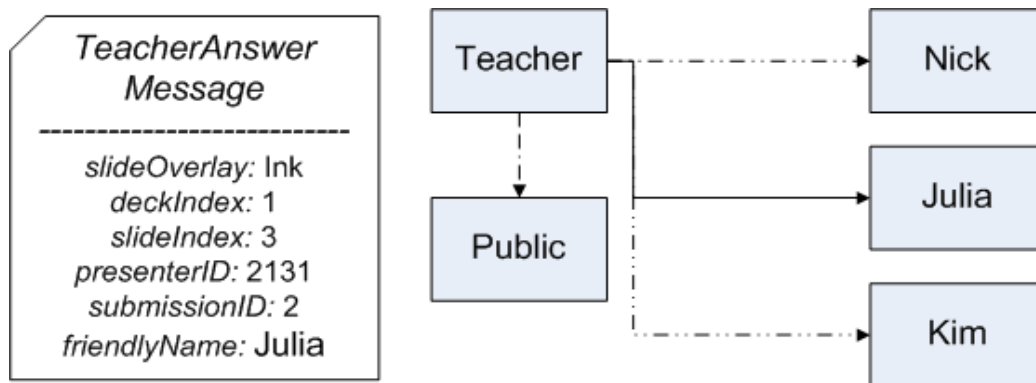


Figure 5. Private teacher to student messaging protocol. The message sent is shown on the left. Solid arrow lines indicate that the message was received and accepted. Dashed arrow lines indicate that the message was received but rejected and not processed. Only the tablet of the student whose *friendlyName* matches the one in the *TeacherAnswerMessage* will accept and process the message.

3.1.3 Effects on other system components

The introduction of private teacher-to-student messaging made it necessary to slightly modify two other components of CLP: the *StudentSubmissionMessage* and the way student submissions are stored on the teacher tablet.

The change to *StudentSubmissionMessage* was straightforward. The message already contained a *deckIndex*, a *slideIndex* and a *friendlyName* of the sender, which allowed the teacher computer to map the submission to the correct slide and to identify the student who submitted it. To introduce private teacher-to-student messaging, I added one more field to the *StudentSubmissionMessage*: the *submissionID*. When sending the *TeacherAnswerMessage* back to the student, the teacher tablet will include the *submissionID* originally sent by the student. This allows the student computer to match the teacher comment to the submission the student has sent.

The second change that I had to make was to store the student submission information on the teacher tablet to be able to retrieve it and put in the *TeacherAnswerMessage* when sending a comment to the student. The student submission slides, created by putting an overlay sent in the *StudentSubmissionMessage* on top of a copy of the teacher's copy of the slide, are stored in *StudentSubmissionDecks* on both the teacher and the public tablet. Each deck contains an array of slides. To store the information from the student submission, I added a *studentSubmissionExtension* field to the *Slide* class. Such an extension contains the *deckIndex*, *slideIndex*, *friendlyName* and *submissionID*, all of which can be retrieved easily when creating a *TeacherAnswerMessage* for a given slide.

3.2 Instructor private mode

3.2.1 Purpose

With the implementation of private teacher to student messaging, it became necessary to add another feature to CLP: a private mode for the teacher. The rationality behind this addition was simple: While the teacher was able to send messages to a single student without other students seeing them, the teacher's comments would still be visible on the projector as she was writing them. After all, the public tablet would copy all the teacher's

steps and display them. It was therefore necessary to allow the teacher to disable synchronization with the public tablet.

3.2.2 Implementation

The implementation of the private mode for the teacher differs from other ways of disabling messages, which were already present in the CLP. To toggle student receipt of instructor ink, for instance, the teacher tablet would send a *CPDisableInstructorInk* message to all of the student tablets to indicate that they should not accept any *RTStroke* messages. In the case of the private mode, I wanted the public tablet, as well as the student tablets, to not accept any *RTStroke* or *CPPageUpdate* messages. That way, none of the other tablets would receive the instructor ink or switch to the slide that she was looking at while she was in private mode.

The solution was to disable outgoing messages of certain types on the teacher's computer. Specifically, a new flag called *privateMode* was created. Whenever the teacher switches into or out of private mode, this flag is set to *true* or *false* respectively. Then, before creating and sending an *RTStroke* or *CPPageUpdate* message, the instructor's message sender checks whether the *privateMode* flag is set to *true* and only then does it send the message. The teacher can easily switch between private and public mode by toggling a button in CLP's content panel (see Figure 6).

3.2.3 Erasing in private mode

It is important to note that *RTStrokeErased* is not one of the message types disabled in private mode. This is a conscious design decision. The reasoning behind it is as follows: If the teacher erased in private mode something that was written in public mode and the message indicating that action was not broadcast, no other computer, even the public one, would erase

the stroke. Consequently, if the teacher went back to public mode, the ink that she had erased would still be visible on the projector, but not on her own computer. She would therefore never be able to erase that ink again, and it would forever remain on the projector. As a result, it was necessary to maintain the sending of *RTStrokeErased* messages in private mode.

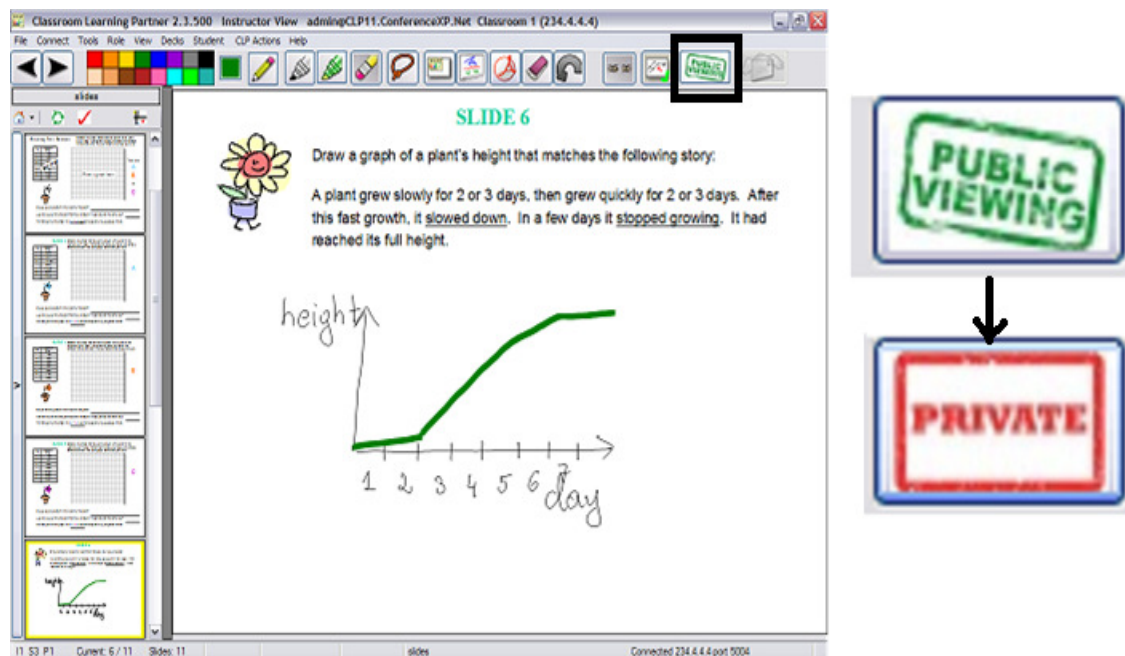


Figure 6. Toggling private mode on and off. The image on the left illustrates the user interface of the teacher tablet, with the button for toggling private mode on and off indicated by a black box. The two images on the right show the two possible icons for the button. When the button says “public viewing”, clicking on it will toggle private mode on and change the button icon to “private”. Similarly, when the button says “private”, clicking on it will toggle private mode off and change the button icon to “public viewing”.

3.2.4 Marking messages written in private mode

One problem associated with the introduction of private mode was to come up with a way of distinguishing messages written in this mode from other messages. It is possible that a teacher would write a private note on a slide, then switch to a different slide, go back into public mode, and after a while come back to the first slide expecting everyone to see the notes that she has written. She might not remember which notes were written in private mode and therefore were not saved on the public tablet and cannot be visible on the projector.

The temporary solution to this problem was to switch the ink to yellow pen when private mode is turned on. The teacher can overwrite this default setting by selecting a different color to write in, but if she chooses not to, she will know that the notes she wrote in yellow ink will not be visible on the projector. Yellow was chosen because we had observed in previous classroom that this color was not well visible on the projector. As a result, the teacher did not use it very often for public comments.

4. Applications

The combination of both new features—the private teacher-to-student messaging and the instructor private mode—has many interesting classroom applications. During trials conducted in a fourth grade classroom at an elementary school in Waltham, MA, I had the chance to instruct the teacher in how to use the new features as well as to observe how she used them in unforeseen applications.

4.1 Applications of private messaging

The first application of private messaging was the one originally intended by the design. The teacher was able to write messages on student submission slides and send them to students by clicking on the send button. Thanks to Brandon Pung's new user interface, the students were able to see the teacher's comments (see Figure 7).

Private messaging also proved useful in a new CLP application written by Neil Chao. Neil's system allows the teacher to randomly shuffle a deck of student submissions and send them to the students for grading. Each student receives a submission that is not his or her own. When sending other students' submissions to individual students, CLP uses my private teacher to student messaging protocol. Figure 8 illustrates how the teacher would use the user interface to randomly send out student submissions.

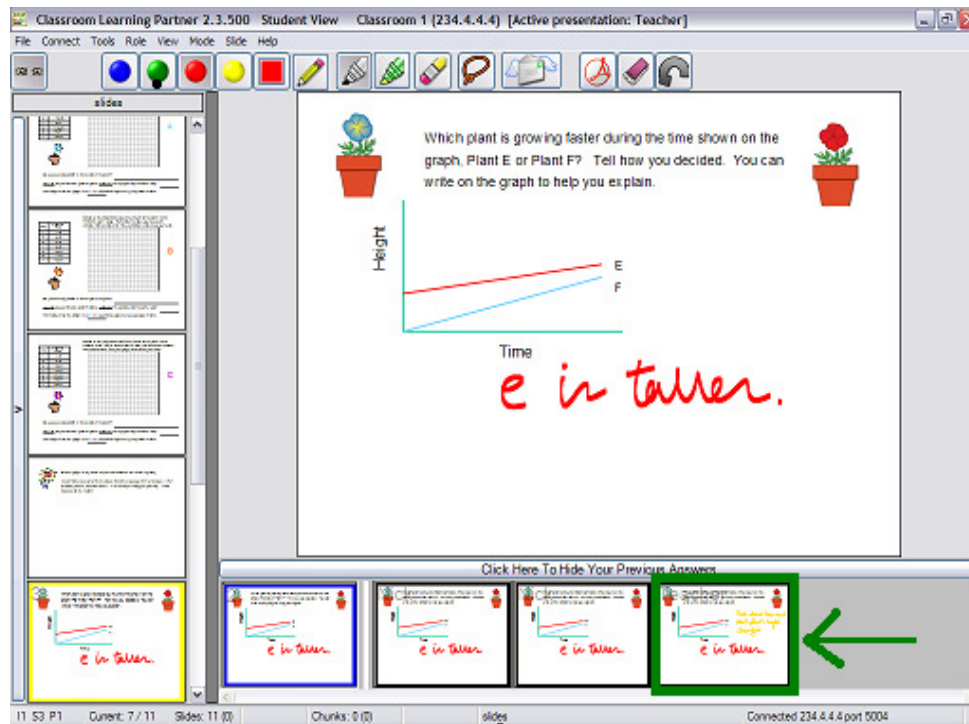


Figure 7. Student's receipt of teacher's comments. The student can view his or her old submission in a film strip that can be opened below the slide. Comments sent by the teacher also appear in this film strip and can be enlarged by clicking on the correct slide icon. Green box and arrow are added for emphasis; they are not part of the user interface.

4.2 Applications of instructor private mode

The original intent of the private mode, which allowed the teacher to write on a student's submission without the other students seeing it, has been tested successfully. The teacher can go into private mode while looking at her own slide, go to a student's submission slide, write a comment on it, send it to the student, go to a slide she wants the students to see on the projector and exit private mode. This process is illustrated in Figure 9. Neither the student's submitted slide nor the teacher's comments are visible during the process.

In addition, the private mode allows the teacher to look at submitted slides without distracting the students. The teacher can simply go into private mode while looking at her own slides and then look through student submissions. In classroom trials performed before the implementation of the private mode, I observed that the teacher would use a cap on the projector to achieve this functionality. It is now no longer necessary to do so. With one click

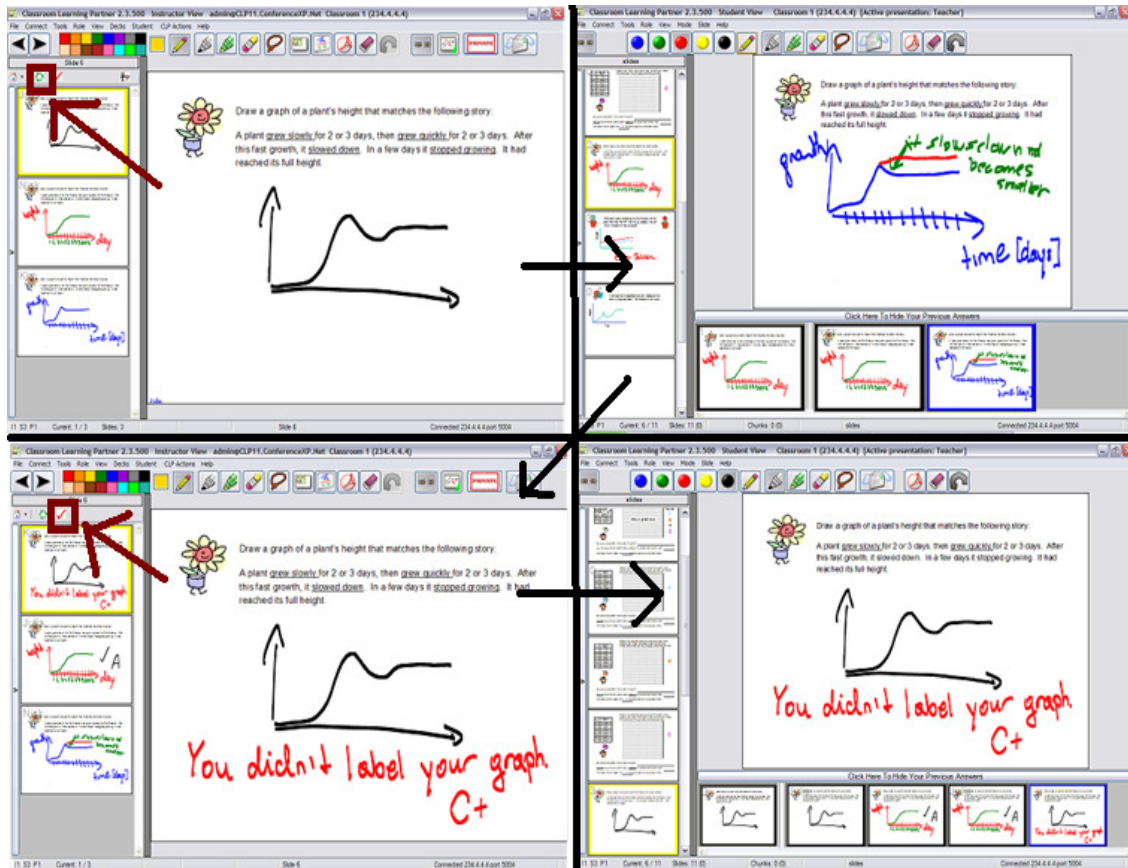


Figure 8. Peer-grading functionality. 1) The teacher clicks on a shuffle button, indicated by a brown box, to randomly send the student submissions to other students. 2) Students receive other students' work, grade it, and submit it. 3) The teacher corrects grading errors if she wishes to do so, and then clicks on the grade button to send the graded answers to the students. 4) Students can see their slide graded by another student, possibly with the teacher's comments.

on the user interface, the teacher can successfully simulate the covering of the projector. Even better, the students are now no longer aware of the fact that she has done so.

Finally, the private mode can be used by the teacher to write private notes to herself. I observed that while looking through student submissions in private mode, the teacher would put little asterisks on the submissions she wanted to later display on the projector, so that she could remember which submissions she liked without showing all of them to the students.

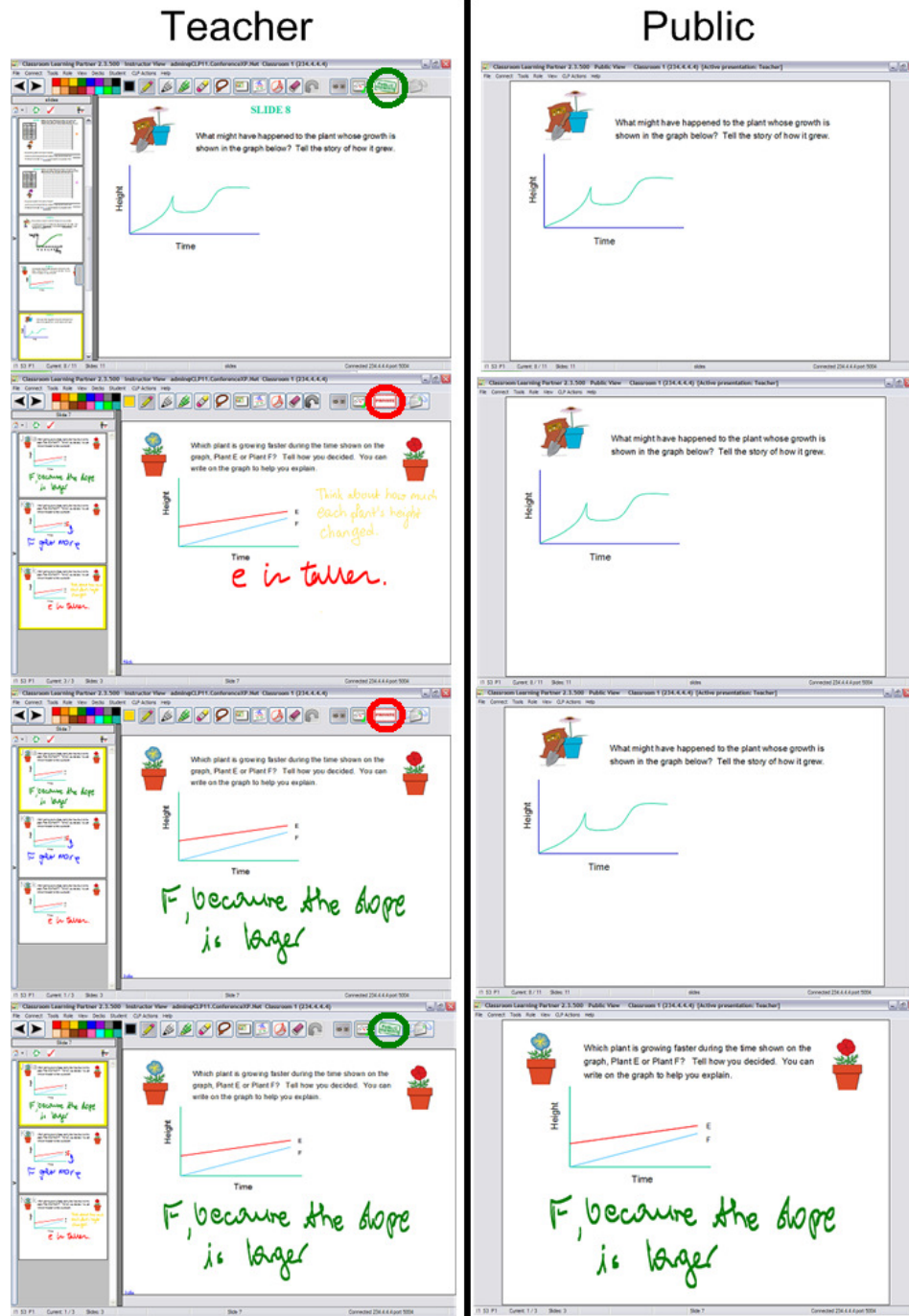


Figure 9. Sample use of instructor private mode. The images on the left show the teacher view. The images on the right show simultaneous public view. 1) The teacher is in public mode. The projector is synchronized with the teacher's tablet. The teacher then clicks on the button to turn private mode on. This slide will now stay on the projector. 2) Teacher selects a student submission and writes on it. No change made on the projector. 3) Teacher looks at another submission. This submission also does not show up on the projector. The teacher now clicks the button to go back into public mode. 4) The teacher is back in public mode and the projector is again synchronized with the teacher's tablet.

5. Future work

There are two more possible extensions that can be implemented to increase the functionality of the private mode and private messaging. First, there is a need for a marking system that would make it easier to distinguish the teacher's private ink from all other ink. Second, one could add a feature that would allow to explicitly send private teacher comments for display on the projector.

5.1 Marking private ink

As explained in section 3.2.4, the current way of distinguishing notes written in private mode from the publicly visible ones is by setting the ink color to yellow in the private mode. In the future, however, a better system will be needed for marking private ink. There are two conceivable approaches to solving this problem.

One possible solution would be to make the strokes written in private mode look different than the public ones. For instance, one could imagine setting a different stroke width in addition to selecting a default ink color in private mode. It is likely, however, that changes in the ink characteristics would not be easily visible for the teacher, especially if she can still overwrite the default ink color at will.

A second approach would be to explicitly mark the private notes. For instance, CLP could automatically draw a distinctive tag, such as a picture of a small flag, in proximity of the private notes. Such a tag would be drawn in the same color as the private notes that it is marking. The implementation of this solution would be quite complicated. For once, one would have to make sure that the mark does not overlap with other comments. In addition, not every stroke drawn in private mode would need its own distinctive mark. After all, it should be sufficient to have only one flag per each message. One message, however, can consist of

many strokes. The use of algorithms from computational geometry would be necessary to determine which strokes form a coherent entity.

Even though no obvious solution exists for the problem of tagging private ink, it is crucial that the teacher be able to distinguish private notes from public ones. A system for marking private ink would be a valuable addition to CLP.

5.1 Sending private ink to the projector

A second possible addition to CLP, one most likely easier to implement, is the explicit sending of private teacher ink to the projector. Right now, while the teacher is able to write a comment in private mode and make it visible to one student by clicking the send button, there is no way to write a comment in private mode and then have it display on the projector. Such a functionality would be desired because it would allow the teacher to prepare a slide without distracting the students from working on their problems. She could later click on a button that would send all the new ink to the public tablet for display on the projector.

While the problem seems similar to sending private messages to students, there are some differences that make the implementation less straightforward. Most importantly, the teacher's comments are stored as separate slides on the student's tablet. Once sent, the comments cannot be altered. The teacher cannot erase them or add new ink for the student to see without resending the message.

With explicit "send to projector" button, however, we would like to maintain the real-time interaction that exists between the teacher tablet and the public tablet. We would like the teacher to be able to erase the message written in private mode and have it immediately erased on the projector. Effectively, explicitly sending private ink to the projector should simply add the new ink to the existing slide on the public tablet.

There are two conceivable ways of implementing this new functionality. First, we could simply send all ink on the current slide to the projector, without checking which strokes are new. This solution, however, might cause trouble when the teacher attempts to erase some of the ink that was already on the projector before. It is possible that only one copy of the stroke would be erased on the projector, while the other copy would remain unaltered, thus seeming like the stroke was never erased.

A more interesting approach would be to take advantage of the *privateMode* flag. Right now, when attempting to send a message, the instructor's tablet does nothing if this flag is set to *false*. Instead, we could add the unsent messages to a queue. We could in fact make a queue of unsent messages for each slide and simply release them when the "send to projector" button is clicked. It would be important to store not only the *RTStroke* and *CPPageUpdate* messages, but also the *RTStrokeErased* messages. The reason for this is that if a teacher writes something in private mode and then erases it before clicking "send to projector", we want the fact that the stroke got erased to be visible to the public projector. One potential drawback of this approach is that messages would be accumulated even if the teacher never intended to send them to the projector. It would be necessary to decide whether the stored messages should ever be disposed of, or if they should be kept as long as CLP is running on the instructor tablet.

Regardless of the implementation, an explicit "send to projector" button for the private mode would be a useful addition and should be considered in the future work on the Classroom Learning Partner.

6. Conclusion

Classroom Learning Partner allows for direct communication between students and their teacher, the teacher and a projector, the teacher and all the students, and now also the

teacher and an individual student. The new functionality I have implemented—private teacher to student messaging and a private mode for the teacher—has multiple applications in the classroom, ranging from the teacher sending private comments to peer-learning.

The extension of the messaging protocol of Classroom Learning Partner which I designed and implemented has increased the robustness of the system in terms of communication and should make CLP an even more useful tool in facilitating student-teacher interaction in math and science classes.

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