Concept Expression via Stamped Images in Classroom Learning Partner

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May 20, 2011

1 Introduction

The ability of students to communicate concepts and ideas is critically important to their education. The better teachers understand how their students understand the concepts being taught, the more effectively they can teach their classes. They can pause to correct misunderstandings and spend less time on material the students already understand—perhaps from a previous class. As the educational psychologist David Ausubel puts it, “The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly” (Ausubel 1968, vi). My 6.UAP project facilitates student communication of quantitative concepts through the introduction of stamped images to a classroom interaction system called Classroom Learning Partner.
2 Background

2.1 Background Overview

My 6.UAP project is sponsored by the INK-12: Interactive Ink Inscriptions in K-12 project (INK-12), a joint effort between MIT and TERC, Inc. to investigate the role of wireless pen-based technology in enhancing K-12 education. Classroom Learning Partner (CLP) is the tablet software being designed and implemented by INK-12 as a wireless pen-based classroom interaction system. With CLP, INK-12 carries out its experiments and studies of how various applications of the technology can affect the K-12 classroom learning experience. The stamps implemented in my 6.UAP project will support INK-12 as an additional education-enhancing application of technology to be studied. In particular, they enable us to investigate the tradeoff between student free-hand drawing and the use of copied images—some drawn by the students themselves.

2.2 INK-12 Project

The INK-12: Interactive Ink Inscriptions in K-12 project aims to study the use of a wireless network of tablet computers for enhancing education in the STEM subjects of science, technology, engineering, and mathematics. INK-12 targets the current lack of tools for students to engage in the communication and representation of quantitative STEM concepts. Representations of STEM concepts include graphs, maps, sketches, and notes, which are difficult to create and manipulate with only a keyboard and mouse or only a pencil and paper. The two principal investigators—Dr. Kimberle Koile of MIT and Andee Rubin of TERC—hypothesize that wireless pen-based technology will prove to be a good solution and will
improve learning through the facilitation of both student-student and student-teacher communication.

2.3 Classroom Learning Partner

2.3.1 Overview

Classroom Learning Partner (CLP) is the tablet computer software being developed by the INK-12 project. The origins of version one of CLP (Koile et al 2007, 2010) can be traced to a simpler wireless presentation system called Classroom Presenter that was designed to be used in undergraduate lectures (Anderson 2004). Classroom Presenter and CLP allow students to wirelessly submit their answers for in-class exercises to their instructor. Now under the INK-12 project, CLP is moving away from that original presentation slide model of interaction. Instead, the current version uses the C# Windows Presentation Foundation (WPF) framework to more easily support an electronic notebook metaphor as the basis of interaction.

Classroom Learning Partner supports three modes of operations: instructor, student, and projector. Instructor mode allows the classroom instructor to author curriculum, review submitted student work, and project anything onto the projection screen. During curriculum authoring, the instructor is presented with a new menu of options to add content to pages of an electronic notebook. All content may be moved around or deleted. The author may also resize the stamp by clicking and dragging its lower right corner. See Figure 1 for a screenshot of the authoring interface.
Figure 1: Instruction Mode Editing. The ribbon menu at the top contains the selection of objects the instructor may add to the page. On the page is a stamp the author created by inserting a stamp picture.

When finished creating curriculum, the instructor may save the notebook and have each student open it during class in student mode. As students finish work on the curriculum, they may submit their work to the instructor for instructor review. The instructor can then view the student submissions in a filmstrip and can choose to create a display of one or more submissions and then send that display to the projector machine for public display.

Projector mode displays a full screen of whatever the instructor chooses to send to the projector via instructor mode, while hiding certain details such as the name of the student whose work is shown. Student mode consists of a filmstrip of notebook pages, a main view for
the page they are working on, and a ribbon menu of tools with which they may answer the questions presented to them.

It is in this new version of Classroom Learning Partner that I integrated stamps as an additional tool with which students can create answers to questions.

3 Stamp Implementation

3.1 Specifications

The role of stamps was to aid students in answering particular types of questions that required repetitive illustration. Example problems were constructed to help understand how to specify the stamp design. In one problem, students were asked to complete patterns. The idea was that if the students were asked to complete the pattern with three or more pictures, this would be tedious for the student, and the time spent on creating the repeated illustrations would detract from thinking about the pattern-related concepts the problem was designed to test. This situation would be especially the case for patterns with complex, difficult-to-draw elements. One such example problem asked students to explain their understanding of fractions with questions such as “If \( \frac{1}{4} \) of 16 flowers are purple, how many are purple? Show your work.” To show their work, students often want to draw sixteen flowers to divide them into four equal sections. Being able to create one flower and “stamp” identical versions greatly shortens the time spent drawing, allowing students more time to spend thinking about the concepts behind their drawings. See Figure 2 for an example.
Figure 2: Example stamp problem. The above problem tests division and requires the repeated illustration of images to complete the exercise.

Before diving into implementing a polished version of stamps fully integrated with CLP, it was important to determine the specifications that would make stamps most useful in the classroom. We needed to decide exactly how the stamps should be manipulated in order to be used intuitively and easily by students. These stamp specifications were determined through an iterative process of prototype testing. Code for these various versions of stamps was written in standalone applications, tested, and then a final version was integrated with CLP.

The model of interaction we were designing for first involves an instructor creating a stamp whose content is either empty or is a pre-selected image. Students then use that stamp to create and place copies of the stamp’s image. With the blank stamp, students draw their
own image inside the stamp boundaries and then can make copies of that image. Initial brainstorming yielded four ideas for placing and moving stamp images:

**Idea 1: Place finger on stamp.**

- **Pros:** Dedicating a new input mode to stamp interaction creates clear expectations for what interaction will do, i.e. by eliminating the pen as a tool to interact with stamps, there will be no confusion with how the pen is to be used. Allows user to use the pen to draw/color on both the stamp and stamped images.
- **Cons:** Requires transition between fingers and pen, which may be an annoying requirement.

**Idea 2: Place pen on the stamp.**

- **Pros:** Most intuitive action.
- **Cons:** Doesn’t allow the user to draw/color on the stamped image.

**Idea 3: Place pen on area between stamp and bounding box after hover over stamp.**

- **Pros:** Allows user to draw/color on the stamp.
- **Cons:** Too easy to accidentally hover over stamp while drawing around the stamp, leading to unintentional movement of a stamp or stamp image. Area between stamp and bounding box can be annoyingly small.

**Idea 4: Place pen on stamp handle after hover over stamp.**

- **Pros:** Allows user to draw/color on the stamp.
• Cons: Requires decision over placement of handle, e.g. a handle on the right may be ill-suited for left-handed users. It will not be immediately obvious to users that a handle will appear on hover.

Of these initial ideas, ideas 1 and 2 were chosen as viable choices to test first. For the stamps that required pen interaction, e.g. coloring, permanent handles were added to the stamp to be used to create copies of the stamp image onto the main page (See Figure 3). The handles then would disappear after images were placed and appear upon hover as discussed.

![Stamps in prototypes](image)

**Figure 3: Stamps in prototypes.** The stamps are boxed in squares to differentiate them from their stamped images. The two stamps on the left have handles for pen interaction. The two stamps on the right were to be dragged via finger touch.

On April 4, 2011, these two stamp prototypes were tested in a 4th grade class at Northeast Elementary School in Waltham, Massachusetts. Few mistakes were observed when students created stamp images with their fingers. However, left-handed students were observed to struggle with dragging the handled stamps with their pens. Their hands and arms were obscuring their vision of the stamp so simultaneously moving the stamp and checking if the stamp’s image was exactly where they wanted to place it was difficult. As a result, a new prototype was created with handles on the bottom.

On April 6, the prototypes were tested in a 5th grade classroom at Baldwin Elementary School in Cambridge, MA. Students often marked within the stamp image when attempting to
drag. We hypothesized that this was either because students missed the handle or because students thought they could create a stamp image by dragging the image itself rather than the handle (See Figure 4).

![Figure 4: Stamps in second prototypes.](image)
The stamps for pen interaction have their handles on the bottom. Here is an example of the stray marks observed on April 6, 2011. The stamps for finger interaction remained the same.

As a result, a third iteration was made, except this time with an extended handle. This version was designed to control for the possibility that the students were missing the handle with the pen. We also offered an additional option with the extended handles on the top of the stamps instead of bottom. The very next day on April 7, 2011, the new prototypes were tested again at Baldwin Elementary, this time in a 4th grade class (See Figure 5).

![Figure 5: Stamps in third prototypes.](image)
The third prototypes offered handles that were extended far away from the stamp image. Here is an example of the stray marks observed on April 7, 2011. The stamps for finger interaction remained the same.
The resulting stray marks mostly appeared next to the handles, demonstrating that students were indeed missing the handles.

By the end of prototype testing, we had a refined stamp model that used pen input to compare with a stamp model that used finger input. At every day of testing, students preferred the pen-input stamps over the finger-input stamps, even when the early version of the pen-input stamps caused many more errors in use. Reasons included the annoyance of switching between pen and finger, low accuracy of placing stamped images with a finger, the blocked vision of the tablet screen when fingers were used, and the increased friction against the finger when dragged over large distances. The final conclusion of prototype testing was that the stamp should be manipulated with pen input on sufficiently large handles.

3.2 Final Implementation

The final version was written to fit both the user interaction model and programming model of Classroom Learning Partner. In addition to the student interaction tested in the prototypes, stamps needed to be created using Classroom Learning Partner’s authoring tool. Electronic notebook authors must be able to place and customize stamps during curriculum preparation, which requires different interaction than when students use the stamps to create drawings. Regarding programming models, Classroom Learning Partner uses the Model-View-Controller (MVC) programming paradigm. Prototype code did not adhere to the MVC pattern and thus required a rewrite to integrate well with the rest of Classroom Learning Partner.
The final stamp features a much larger stamp handle, authoring mode features, additional user affordances, and an alternative version of the stamp. The large stamp handle reflects the feedback collected from prototype testing. It also was shaped to resemble a physical stamp handle as an affordance to indicate that the user should use the handle to create a stamped image. The handle also turns green when the pen hovers over it to serve as an additional indication that the handle is meant to be used to make stamped images and to inform the user when the handle has been “grabbed” to be dragged around for the placement of a stamped image (See Figure 6).

![Figure 6: Final stamp form.](image)

The stamp handle more resembles the trapezoidal shape of physical stamps and is much larger in order to reduce missed pen hits. The stamp on the right shows the stamp appearance when a pen is hovered over the stamp handle and when the user has “grabbed” the stamp.

To fulfill the needs of the authoring tool, stamps needed to have a way to be added, moved around the page, resized, and deleted. This functionality also needed to exist for all page objects such as text boxes and static images, and had not yet been implemented in Classroom Learning Partner. Recall that CLP was being rewritten from scratch using the C# WPF platform. Using that platform, I implemented an abstract way to manipulate all page objects
when authoring. Ribbon menu buttons allow the selection of a page object to be added (See Figure 7).

**Figure 7: Adding Page Objects.** The ribbon menu here shows the selection of page objects the author may add. Stamp Picture and Stamp Path are the two types of stamps that may be added. The difference will be described shortly.

To offer ways to move, resize, and delete a page object, a container box appears when the pen is hovered over a page object. On the container box is a rectangular gray bar at the top and a red square button at the upper right. Clicking and dragging the gray bar moves the page object and clicking the red square button deletes the page object. Clicking and dragging the lower-right corner will resize the stamp (See Figure 8).
**Figure 8: Authoring Tool.** On the page is a text box with custom text ready to be moved or deleted. The gray rectangle can be used to move the textbox by dragging it around the page. The red square can be clicked to delete the textbox. The lower right corner may be dragged to resize the stamp.

An additional version of the stamp was written to enable students to create their own stamp image. This alternative stamp maintains the ease of making repetitive illustrations while still allowing students to be creative and to think critically about how to represent their solution to a problem. In this alternative version with custom stamps, the stamp tracks any pen strokes created or erased inside the stamp area so it knows what to copy and move when students make stamped images.
3.3 Classroom Testing

Newly equipped with fully integrated stamps, Classroom Learning Partner was ready to be deployed to a 4th grade classroom for live testing. During the week of April 25-29, 2011, Classroom Learning Partner was used with various electronic notebooks, each with its own set of curriculum to be tested in the classroom. Figure 9 shows a photograph of a student explaining a math fraction problem by creating and placing a balloon stamp.

![Figure 9: Stamps in Action. A student using a stamp to complete her classwork in CLP’s electronic notebook.](image)

The new stamps were met with positive reviews. Students liked using the pen to create stamps and stamped images. The use of stamps was so intuitive and easy that students focused solely on their math problems rather than on the technology.
Seven special needs students also used CLP during this week of testing and two days the following week. This group of students particularly favored the stamps because it meant less drawing, a task that was particularly difficult for many of them due to difficulties with fine motor control. They were able to effectively use both the stamps containing pre-authored images and the blank stamps requiring their own drawings. Figure 10 shows the use of two stamps created by one of these students to solve a multiplication problem.

![Image of a stamp using example](image)

**Figure 10: Special-needs student work using student-drawn stamps.** This example shows work on a problem offering the assistance of a custom stamp. The cat and person only needed to be drawn once each before writing an explanation for this problem was possible.

Students who possess the fine motor skills to draw the same picture easily and repeatedly still benefit from the stamps because the stamps are much faster and less tedious to use. So they too save time in creating multiple simple drawings, as shown in
Figure 9. Some of the students additionally felt motivated to invest time in creating more detailed, accurate drawings knowing the stamps would take care of the repetition, no matter how complicated. Figure 11 shows one such example.

Joanne has 5 apples. 2 of them are red, and the rest are green. Make an apple stamp using the blank stamp, and create a picture of Joanne’s apples. Then color in the apples to show the answers to the questions.

<table>
<thead>
<tr>
<th>What fraction of the apples is red?</th>
<th>$\frac{2}{5}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>What fraction of the apples is green?</td>
<td>$\frac{3}{5}$</td>
</tr>
<tr>
<td>How many apples are green?</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 11: Detailed images in student-drawn stamps. This example shows work on a problem offering the assistance of a custom stamp. The student drew a red apple on the stamp and copied it twice onto the page, then erased it, drew a green apple on the stamp, and then copied it three times. The apples stand out in this example due to the completeness in features—leaves, stem, and body—and in the variation in color across the image.

Ultimately, the lauded integration of the stamps into the classroom was an encouraging signal that Classroom Learning Partner, and stamps in particular, could provide valuable classroom assistance. Stamps helped all students express quantitative ideas easily, quickly, and succinctly.
4 Future Work

4.1 Resize Affordances

There is currently limited affordance that indicates to an author that a page object may be resized. The only signal that exists is a change in the shape of the pen cursor when the pen hovers over the lower-right corner of the page object container box. A popular resize affordance that could address this problem is showing ridges at the resize corner so that it resembles a grip.

Figure 12: Resize Affordance. The three ridges in the bottom right corner of this image are an example of a fairly universal signal that the corner may be clicked and dragged to resize the window.

4.2 Distinguishing Stamps from Stamped Images

During final testing of Classroom Learning Partner in late April, some students confused the original stamps with the stamped images when solving math problems. One example occurred when a student asked for help on a particular math problem involving flower stamps. When the student teacher asked the student how many flowers were on the screen, the student replied “five” when in fact there was one stamp and four stamped images. This lack of distinction led to confusion over how to solve the problem.
Figure 13: Confusing Stamps with Copies. In this fraction problem involving flowers, the stamp can be seen placed very closely to the work area where stamped images are placed.

A solution would be to encourage authors to place stamps next to the problem statement instead of below it. Additional testing showed that this placement did indeed solve the problem—no students were confused when the stamps were moved away from the student work area. (See Figures 10 and 14 for examples.)
Ken has 8 flowers. 1/2 of the flowers are purple, 1/4 are red, and the rest are yellow. Use the flower stamp to create a picture of Ken’s flowers. Then color the flowers to help you answer the questions.

How many flowers are purple?

**Figure 14: Separating Stamps from Copies.** In this adjusted fraction problem involving flowers, the stamp can be seen placed far away from the work area where copies are placed.

### 4.3 Automated UI Testing

There are numerous combinations of user interaction combinations that must be interpreted correctly by Classroom Learning Partner. Ensuring that these combinations are handled correctly is currently tested by inspection of code and manual testing. However, experience has shown that manual testing always tedious and often not comprehensive. Interaction-related bug fixes during testing days have occasionally introduced new bugs that were not discovered until students pointed them out during live testing. While good abstraction and attention to detail during coding can mitigate such accidents, there is no substitute for real input testing to ensure quality.
Automated testing can provide a non-tedious solution to test program behavior and response to all combinations of input. Similar to the popular Selenium testing framework for web applications, application testing frameworks for WPF can be used to automate quality assurance. One such framework for WPF is TestComplete by AutomatedQA. With products like TestComplete, sets of user actions may be recorded as test cases to be repeated at a click of a button. In this way, test cases will not be forgotten and valuable developer time is spent on manual testing.

5 Conclusion

The stamps in Classroom Learning Partner help students express repetitive and difficult-to-illustrate representations of math and science. When students are no longer distracted by the difficulty of illustration or tedium of repeated drawing, they can spend more time and focus on thinking about and learning the core concepts that the curriculum is designed to teach. With students having enhanced ability to express the ideas behind their thinking in problem solving, teachers can more fully and quickly understand where a student’s thinking has gone astray or confirm that a student fully understands the concepts being taught.

Thus CLP’s stamps facilitate both teaching and learning in the classroom and as a result, will continue to be a powerful and versatile tool in elementary math and science classrooms.
6 References


