Process Pad: A Low-Cost Multi-Touch Platform to Facilitate Multimodal Documentation of Complex Learning

Shima Salehi, Jain Kim, Colin Meltzer, Paulo Blikstein
Stanford University School of Education
Stanford, CA, U.S.A.
{salehi; jainkim; cmeltzer; paulob} @stanford.edu

ABSTRACT

This paper introduces Process Pad, an interactive, low-cost multi-touch tabletop platform designed to capture students' thought process and facilitate their explanations. Process Pad is designed to help students improve their thinking skills and meta-cognition in various subjects. The system is intended to dynamically externalize how a student arrives at the final answer. Process Pad enables the documentation of students' think-aloud narratives that would otherwise be tacit. Our focus is on identifying and understanding key themes in creating opportunities for students to externalize and represent their thought process using multimodal data. From our user observations, we gleaned four design perspectives as essential criteria based upon which we form our design decisions: flexibility, tangibility, collaboration and affordability. Our initial results show that for many users explaining their reasoning or problem-solving procedure is a challenging activity in itself, and for learners to be able to deepen their understanding by narrating or re-enacting a process there would be many intervening steps. To address these challenges we designed scaffolding activities, which made use of the system's affordances to improve students' explanation skills.

Author Keywords

Tangible interaction embodied and embedded learning, design rationale, self-explanation, scaffolding.

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): H5.2. Information interfaces and presentation: User interfaces. K.3.m Computers and education: Miscellaneous.

General Terms

Design, Experimentation, Theory

INTRODUCTION

Most teachers would agree that it is not an easy task to determine the causes of students' misconceptions. Engaging students in assessment or clinical interviewing activities, albeit useful for many purposes, do not achieve at capturing students' thought process "as it happens," thus educators cannot easily comprehend the origins of students' knowledge. Explanations can be one avenue to make the internal thought process more accessible to both educators and students, improving evaluation and feedback. Nevertheless, there are few methods and technologies that allow students to explain their thought process. Small Group Work or Peer Tutoring [17] are among them, typically employed to address the lack of opportunities for both teachers and students to document students' learning process.; nevertheless, even by these methods it is hard for teachers to monitor students closely and give timely feedback. Clickers are another existing technology used to encourage explanations and facilitate small group discussions [10], providing a way for students and the teacher to see if the class has come to a consensus, and discuss their choices within small groups otherwise [10]. However, these technologies only allow for simple multiple-choice questions, whereas oftentimes teachers want to engage students in open-ended responses as well, supporting multimodal feedback such as sketches or gesture.

There are, however, other technologies which support multimedia-enhanced narrative activities, such as Jabber Stamp [12], and TView [11]. In the case of the Mazalek and Davenport's study with TView [11], the purpose was to enhance multimedia storytelling experience. The study suggests that tangible embodiments of interactive narrative can support a stronger psycho/physical relationship to the story world than is supported by more traditional graphical interfaces. Although, the technologies support a seemingly similar tangible multimedia experience they are not intended to facilitate student explanations or incorporate directly into the classroom. Process Pad, while supporting multimodal feedback, is specifically designed for educational use in the classroom, focusing on students' explanation process and metacognitive skills.

Also, Fischer and Eden's earlier work on the Envisionment and Discovery Collaboratory (EDC) [7], incorporates physical objects with a tabletop environment, in the service of collaborative problem-solving and discussion. Enhancing collaboration through interactive tabletop technology is another key feature of Process Pad. However, while EDC supports collaboration in more professional environments with sophisticated visualization and virtual modeling technologies, Process Pad focuses on collaboration among

TEI 2012, Kingston, Ontario, Canada, February 19 – 22, 2012.
© 2012 ACM 978-1-4503-1174-8/12/0002 $10.00

students, and their teachers with more low-cost multimedia technologies.

Therefore, the research goal of creating Process Pad is to explore the design space of tangible, embodied and embedded interaction to address a learning problem of assessing learners' thought process.

Learning Problem

Students often have difficulty explaining their thought process, and teachers have difficulty assessing students' understanding implied through traditional worksheets and class work. One of the reasons for this phenomenon could be students' lack of sufficient explanation skills, which can be taught, improved, and practiced. However, focusing on individual performance, and standardized tests, today's education system provides little time for students to practice this skillset. Additionally, strong explanation skills not only facilitate the assessment process, but narration and re-enactment of one's own discoveries and thought is a rich learning opportunity.

THEORETICAL AND PEDAGOGICAL BACKGROUND

Constructivists believe that students construct knowledge by adapting their schema when they are exposed to new information through their experiences in the world [6]. Thus, learning does not simply occur through knowledge transmission from the educator or books to students. Instead, learning occurs when students themselves are in charge of improving their previous ideas towards more sophisticated understanding by interacting with the world, embarking from existing models and schemata. Process Pad is designed to provide a scaffolded environment, which facilitates knowledge-construction process. By using the system students are able to verbally and visually explain, as well as view model explanations provided by peers or educators. This allows a child's iterative knowledge construction instead of only providing instant feedback of whether her answer is right or wrong. The feedback system was inspired by the benefits of peer and small group work [17]. Furthermore, unlike peer discussion and small group work, Process Pad enables detailed documentation of the process, providing an assessment opportunity for both teachers and students. Process Pad also, provides students with opportunities to enhance metacognitive skills at their own pace, while acknowledging their learner's own pace and epistemology. Finally, it enables for multiple entry points into learning [7].

Learner's Mental Models, Accommodation, Assimilation

Ackermann [1] emphasizes the necessity for learning theories to consider resistances toward learning – students' schemata and mental models are oftentimes robust and not simply "waiting" to be replaced. In this regard, Chi suggests that the most promising type of intervention is the one in which students are responsible for detecting the inconsistencies between their mental model and the formative model, because students themselves are in the best position to detect this gap, "so they may fix them, consistent with common sense that didactic instruction is less effective than constructive learning" [4]. Hence, Chi asserts that the way to solve the conflicts between students' mental model and a formative model, is by providing students with opportunities to reflect, self-question, or self-explanation. Accordingly, we leaned toward providing a scaffolded environment for students to explain their thought process, hence they will have opportunities to detect and solve misconceptions.

Self-explanation that Matters

We are cautious that not any kind of explanation would lead to improvement in learners' mental models. According to Renkl [13], principle-based explanation is among constructive learning methods. A principle-based explainer first tries to define the meaning of a problem by explaining the goal of the problem and the needed structure to solve the problem.

Furthermore, Aleven and Koedinger's [2] study shows the positive effects of prompting students to self-explain during problem solving. They have discovered that students' self-explaining during problem solving is more beneficial than explaining the provided example study in a computer-based tutoring system. Renkl, Stark, Gruber, and Mandl [14] also discuss that, by providing a short self-explaining training, students are more willing to use self-explanation during problem-solving activities, and they are more successful in solving whether it is a near-transfer or far-transfer problem.

Considering all the above studies, we have attempted to design Process Pad's activities in a way that enhances learners' principle-based self-explanation during problem-solving. During these designed activities, users are enabled to record their sounds and/or images while explaining.

Nevertheless, a new domain could not be learned solely by just self-explanation. Thus Process Pad also has a meta-frame which provides step-by-step instructor explanations and examples that are recorded and saved in the internal database. Students have access to the examples and are able to watch them on Process Pad.

Moreover, Process Pad allows users to utilize tangible manipulatives and common classroom objects, such as paper, pencil during problem-solving activities; so students can comprehensively record their interactions with these tools. Providing learners with tangible tools to explain their thought process is beneficial, as many scholars have pointed out, and as tangible interfaces and alternative input modes become more prevalent, this feature will be increasingly important [1].

DESIGN PERSPECTIVES

The four main design perspectives that we have chosen as the essential criteria in designing Process Pad are:

Flexibility

Process Pad is designed to be a platform. People of all ages can use it with any subject matter they choose. Since it is an open platform, the users can easily add their own activities to the activity library.

Tangibility

Process Pad is designed to be as versatile and easy for the users as a piece of paper. Process Pad can be used with *common classroom objects* – the usual worksheets, papers, and other manipulatives. Teachers can add activities in a digital format to the library, but also just bring the worksheet they are using every day in the class on to the Process Pad. Tangibility and use of familiar objects is one of the most important differences between the system and other digital tools, such as an iPad or smart phones.

Collaboration

The system is designed to encourage both individual and group work. Process Pad is designed to support synchronous and asynchronous collaborations.

Affordability

As a principle, the hardware is built using low-cost materials and do-it-yourself technologies. The software is developed based on open-source, free resources. The price of hardware including the price of a short throw projector is about sixteen hundred dollars. With a regular projector the price of the whole system would be less than five hundred dollars. Both prices can be considered reasonable in comparison with the price of similar product, Microsoft surface, which is between seven to ten thousand dollars.

FUNCTIONAL PROTOTYPE

Technology

Process Pad is a multimedia, multi-touch platform where students can place a piece of paper and other tangible manipulatives on the surface and mark them with digital "dots" by just using their fingers. These "dots" can include audio, image and video recordings (see video at: http://bit.ly/rpZne3).

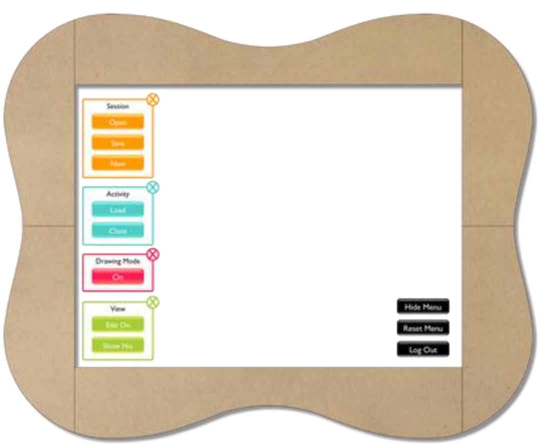

Figure 1. The interface of Process Pad

Hardware

The hardware is a fully functional multi-touch surface, built using do-it-yourself, open-source techniques. The multi-touch surface uses the Frustrated Total Internal Reflection (FTIR) technique [9] along with open source software to detect finger touches on the surface. The main components of the hardware are: a strip of infrared (IR) LEDs, silicon surface, short-throw projector, infrared camera, transparent acrylic sheet, and frame. The hardware allows for projections on to paper and up to 30 simultaneous touches.

We used an acrylic sheet, with distributed IR LED strips around it in a way to have approximately one LED per 1/2 inch. For the computer to detect finger movement on the surface, the frustrated IR escaping from the surface needs to be captured with an IR camera. We modified a low-cost PS3 Eye camera and replaced the built-in IR light filter with a natural light filter so that the natural light would be blocked and IR would pass through the camera lens, and to secure more reliable filtering, we also placed an external natural light filter on the outer side of the IR camera lens. The surface rested upon a school-size desk.

To project the screen on the acrylic sheet, we created a projection surface with a vellum paper on the top of the acrylic surface and placed a short throw projector underneath where it would not to block the IR camera's vision. However, having a vellum paper on top of the acrylic made detecting finger touches more difficult for the IR camera. Thus, we added a silicon layer to the back of the vellum paper to increase the friction between the vellum paper and the acrylic sheet to have stronger touch detection on the surface. As the silicon layer increased the resolution of touch detection, having extra objects such as students' own paper sheets or manipulatives would not distract the main functionality of the system.

Figure 2. The set up for Process Pad

We built a customized wooden frame for the surface to implicitly suggest the place for each user to stand. An external microphone was connected to the frame to record sounds and a video camera was placed above the surface for video recordings.

Software

The software for Process Pad enables the hardware's multi-touch ability by using Multitouch for Java (MT4J)[1] library and Community Core Vision[2] software. Community Core Vision (CCV) bridges the visual signals sense by the IR camera and the Java code..

Utilizing the above process, we implemented the following features:

- User can leave "dots"

Users place a "dot" on the surface by touch-and-hold, and then make an audio, picture, or video recording that is associated with the physical spot.

- Users can load scaffolding activities

Instructors or designers can load activities to scaffold students to learn how to use Process Pad or to learn to explain.

- User Login

Users are required to login so the saved work is associated with the individual users.

- Customizable Menus

Menus are customizable in sizes, layout and orientation so that they can be accessed from any side of the Process Pad.

- Different Modes

Two modes have been defined for the system: explanation mode and drawing mode. In an explanation mode, the surface is sensitive to touches. In drawing mode, however, the surface does not respond to touches except for the menus, thus students can easily draw and write on the surface without accidently triggering the system.

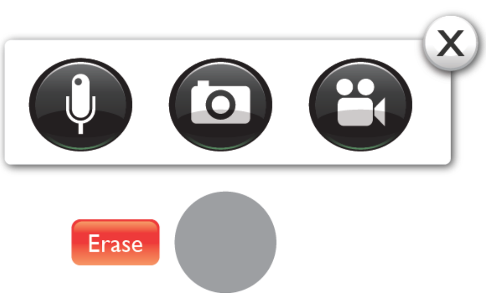

Figure 3. The "dot" menu

[1] For more information on the open-source framework refer to: http://www.mt4j.org/mediawiki/index.php/Main_Page

[2] For more information on the open-source software refer to: http://ccv.nuigroup.com/

- Simple Gestures

The software uses intuitive multi-touch gestures to interact with the "dots" and menus on the multi-touch surface, such as drag, pinch, and zoom.

OBSERVATIONAL STUDIES Study Design

We conducted three studies. The aim of these studies was to observe Process Pad in use and collect insights for further improvements. The main purpose was to explore how our design decisions impacted interactions which in turn create, shape or constrain opportunities for learning to explain and explaining to learn.

Our studies were with 2^{nd} graders, a 3^{rd} grader and a 5^{th} grade student. We also had some early unstructured tests with children as young as 4 years old and also with graduate students.

The first design study was conducted during a second grade's class session. We had access to 14 students. We conducted a more specific study with two second graders randomly drawn from the class as our main subjects of observation. Additionally, we also had 12 other second graders briefly play with the initial prototype. We gave a 5-minute introduction, followed by a 2-minute interaction to check if the students understood how to use the prototype. Then, we gave around 5 minutes for the students to solve a math problem using the prototype and to leave sound dots. After that, we let the students watch a video of them completing the problem and asked if they wanted to make changes.

For the following user study with a 3^{rd} grade and a 5^{th} grade student we spent around an hour with each of them. We asked them to explore a series of scaffolded activities intended to help them learn to explain, and closely observed them during this process.

We video-recorded all the user interactions and collected field notes that included descriptions of behaviors and quotes from the users. We analyzed our observational data using qualitative data analysis methods in order to evaluate changes found in the users' explanation through interacting with Process Pad and study whether the explanation in a greater extent becomes a way for the users to externalize their thought process.

Process Pad Activities

During activities, users had access to tangible and physical objects to utilize during their problem-solving in order to facilitate their thinking process or communicate their ideas [1]. These provided activities could be categorized into five major groups as following:

Starter Activities

These activities pursued the goal of familiarizing users with Process Pad and its functionalities. One example of this group is the "body parts" activity. In this activity, an image of the human body with lines and dots pointing to different parts was loaded on Process Pad screen, and then we had the users label each part with audio, image or video naming each part.. At the end of these activities, users would have tested all main functionalities of Process Pad.

General Scaffolded Activities

With these activities we sought the goal of teaching users how to construct their explanation in meaningful steps. For example, we provided users with four scenes of a comic strip that were out of order. Then we asked them to put the scenes into a meaningful sequence and add a verbal explanation as to what is happening on each scene and why they had chosen that order.

Subject Specific Scaffolded Activities

An example of an activity in this category could be called math comic strip. In this activity, we gave users several steps of a multiplication problem and asked them to put them in order and add verbal explanation to each step revealing the logic behind the choice of that order.

Partially Scaffolded Activities

These activities had the goal of enabling users to explain their own solution in meaningful steps. For example, we provided users with another division problem; however, this time they were not provided with different steps of a solution; instead, they had to come up with their own solution and break it into different steps, and explain each step in connection to the other ones. In this set of activities, users could also utilize tangible objects to support better explanation. For example, they had access to poker chips. Hence, for division problem, they could bring them on process pad and apply the division to a group of chips and video record the process to illustrate their solution.

Open-ended Activities

This category of activities was the final set of pre-loaded activities on Process Pad. They were open-ended problems with no scaffolding. In this set of activities, we gave users a word problem, and observed how they leveraged skills they gained in previous activities to define a solution and explain it through connected meaningful steps. Similar to the previous categories of activities, users had access to physical objects as a tool to help them think about solutions or more clearly explain and document their thought process.

Although dividing the explanation process into several steps could be perceived to be required as a result of Process Pad features, this way of explanation truly formed based on our understanding from the literature of principle-based explanation [13] and our observations from the initial user studies. Based on our observations, breaking down the explanations to several steps encourages users to explain the goal of the problem and justify the structure they have selected to solve the problem. Explaining the solution in several steps, furthermore, externalizes the mental structure users select for solving the problem, it also clarifies this structure for themselves, which help them detect the flaws of their structure and correct them.

Study Results

We will focus on those results that help us identify and understand a way to develop design features to facilitate students' self-explanation.

General Attitude towards Process Pad

In terms of broad audience acceptance, many participants expressed enthusiasm about interacting with Process Pad. In our first user test with 2nd graders, they liked making audio recordings, associating them to a physical spot and playing them back to hear their own voices. However, our older users were also curious about the back-end technology.

Explanation can be challenging

Regardless of their age or background, explanation was a challenging task for the majority of our users. One typical observation was that students tacitly knew how to solve certain problems but not how to externalize their thought. In our third user study with a 5th grader, for example, he said, "I know what to do; I just don't know how to explain it."

Learning to Explain

Our observations in all three studies demonstrate that explaining is a learned skill. Students' explanations were generally too brief and incomplete, especially with younger participants. Often they need to learn and practice explaining. Scaffolds were provided to facilitate "learning to explain," and they proved to be useful. Initially users need a step-by-step instruction about how to explain and what to explain about. Gradually scaffolding would fade away and users became more autonomous.. The activities go from structured to open-ended.

Need for Understanding the "Big Picture"

Often users would plan out steps before they started to explain their process. Understanding the "big picture" is important in creating a clear explanation and essential component of a principle-based explanation. In most cases, students completed the Math problems in their head and had to be prompted to leave sound dots with their explanation. In such cases, they mostly did not capture the big picture in their explanation and as a result their coherency decreased. Hence, in our later user studies, we added prompts to make students envision the "big picture" of the problems when planning the explanation.

Working together

In several cases with multiple users working on Process Pad, it was observed that users were willing to collaborate with each other instead of working separately. We observed both synchronous and asynchronous collaborations. Sometimes users tended to work together and other times an individual's work became a base for another's without necessary being asked to do so in both cases.

CONCLUSION AND DISCUSSION

In this paper, we introduced Process Pad, an interactive, low-cost multi-touch tabletop platform designed to capture students' thought processes and facilitate their explanations. With Process Pad, we tried to explore how to leverage the combination of physical and digital interfaces to give students well-structured environment to practice their explanation skills. We also aimed to record students' thoughts in a medium that best matches their learning style and the associated content. The interaction between hardware and software creates an environment for students to document their explanation in various formats, and its low cost suggests the real possibility of having such devices in public schools as a way to assist teachers and students to document multimodal learning narratives.

REFERENCES

1. Abrahamson, D. Embodied Design: Constructing means for constructing meaning. *Educational Studies in Mathematics,* 70 (1), (2009), 27-47
2. Ackermann, E. (2001). Piaget's Constructivism, Papert's Constructionism: What's the difference? Paper presented at *Constructivism: uses and perspectives in education.*
3. Aleven, V. A., & Koedinger, K. R. An effective metacognitive strategy: Learning by doing and explaining with a computer-based cognitive tutor. *Cognitive Science 26*, (2002), 147–179.
4. Atkinson, R. K., Renkl, A., & Merrill, M. M. Transitioning from studying examples to solving problems: Effects of self-explanation prompts and fading worked-out steps. *Journal of Educational Psychology 95*, 4 (2003), 774–783.
5. Chi, M. Self-explaining expository texts: the dual processes of generating inferences and repairing inferences and repairing mental models. In R. Glaser (ed.), *Advances in Instructional Psychology*. Lawrence Erlbaum Associates, Hillsdale, NJ, 2000, 161-238.
6. Corcoran, A, C. Dershimer, E, L. Tichenor, M, S. A Teacher's Guide to Alternative Assessment Taking the First Steps. *The Clearing House 77,* 5 (2004), 213-216.
7. Cunningham, D., & Duffy, T. Constructivism: Implications for the design and delivery of instruction. In D. Jonassen (ed.), *Handbook of Research for Educational Communications and Technology*. Simon & Shuster Macmillan, New York, 1996, 170-198.
8. Eden, H., & Fischer, G. The Envisionment and Discovery Collaboratory (EDC). Center for Lifelong Learning and design (L3D)
9. Gardner, H. *The Disciplined Mind*. Penguin Books, New York, 1999.
10. Gülbahar, Y. & Tinmaz, H. Implementing Project-Based Learning And E-Portfolio Assessment In an Undergraduate Course. *Journal of Research on Technology in Education 38*, 3 (2006), 309-327.
11. Han, J. Y. Low-Cost Multi-Touch Sensing through Frustrated Total Internal Reflection. In *Proc. UIST 2005, ACM Symposium on User Interface Software and Technology*, ACM Press (2005).
12. Kyei-Blankson, L. Enhancing Student Learning in a Graduate Research and Statistics Course with Clickers. *Educause Quarterly 32*, (2009). Retrieved May, 2011 from http://www.educause.edu/EDUCAUSE+Quarterly/EDUCAUSEQuarterlyMagazineVolum/EnhancingStudentLearninginaGra/192963
13. Mazalek, A., Reynolds, M., and Davenport,G. TViews: An Extensible Architecture for Multiuser Digital Media Tables, *IEEE Computer Graphics and Applications 26*, 5 (2006), 47-55.
14. Raffle, H., Vaucelle, C., and Wang, R. Jabberstamp: embedding sound and voice in traditional drawings. In *Proc. IDC 2007*, ACM Press (2007).
15. Renkl, A. Learning from worked-out examples: A study on individual differences. *Cognitive Science 21*, 1(1997), 1-29.
16. Renkl, A., Stark, R., Gruber, H., & Mandl, H. Learning from worked-out examples: The effects of example variability and elicited self-explanations. *Contemporary Educational Psychology 23*, (1998), 90 –108.
17. Shute, V, J. Jeong, A, C. Spector, M, J. Seel, N, M & Johnson, T, E. Model-Based Methods for Assessment, Learning, and Instruction: Innovative Educational Technology at FSU. *Educational Media and Technology Yearbook 34*, Part I (2009), 61-79.
18. Smith,J, P, diSessa, A, A, Roschell, J. Misconceptions Reconceived: A Constructivist Analysis of Knowledge in Transition. *The Journal of the Learning Sciences 3*, 2 (1993 - 1994), 115-163.
19. Webb, N. M., Franke, M. L., De, T., Chan, A. G. , Freund, D. , Shein, P. and Melkonian, D. K. Explain to your partner': teachers' instructional practices and students' dialogue in small groups. *Cambridge Journal of Education 39*, 1 (2009), 49-70.