

TAP & PLAY: An End-User Toolkit for Authoring Interactive Pen and Paper Language Activities

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ABSTRACT

Hybrid paper-digital interfaces are a promising approach for supporting language activities. The familiarity of pen and paper makes it a particularly attractive media for many user groups, including young children. Digital pens enhance interaction with traditional paper content by playing and recording audio and recognizing handwriting and gestures. Currently, generating custom interactive paper documents involves some programming, limiting its use by many user groups (e.g., educators and families) who might especially benefit from application of hybrid paper-digital interfaces in their practices. To address this need, we developed an end-user Toolkit for Authoring Pen and Paper Language Activities (TAP & PLAY). This paper describes the iterative development of the toolkit, its accessibility for novice non-technical users, and use in three different contexts for early language learning. We demonstrate and document the system's usability, generality, and utility for people who want to create and tailor their own custom interactive paper-based language activities.

Author Keywords

Children; Digital Pen; End-User Authoring Toolkit; Language Activities; Learning

ACM Classification Keywords

H.5.2 User Interfaces: Input Devices and Strategies

General Terms

Design; Human Factors

INTRODUCTION

Even after all the advances in computer interface design, modern computers can be difficult to use or inappropriate for some tasks. Pen with paper, in contrast, is a familiar, flexible, and pervasive interface. Hybrid paper-digital interfaces enabled by digital pens (e.g., Anoto¹) bridge the simplicity of pen and paper interaction with the processing, memory, and

multimodal input/output capabilities of a computer. Digital pen technology has been introduced into a variety of contexts (e.g., [10, 25, 20]) and as commercial products (Livescribe², LeapFrog Tag³). However, creating interactive paper-based content requires programming expertise and access to complex software development toolkits. This paper introduces TAP & PLAY, a pen-based interface for authoring interactive paper materials. It enables non-technical end-users to independently create custom paper materials that work with a Livescribe digital pen. TAP & PLAY could support many applications, but here we document its use for authoring language learning activities.

Many language learning activities are paper-based and may benefit from the capabilities of digital pens. Language development for young children often involves parents and teachers reading picture books with them. Early childhood education classrooms have words written on paper posted around the instructional space. Walls are filled with printed posters, children's artwork, and early writing samples. These materials could be augmented with sounds or audio content. The audio recording and playback facilities of digital pens could also capture audio descriptions by children who are unable to write. When children do learn to write, pencil on paper is often the first interface they use. Digital pens could provide guidance and foster independence in writing. Similarly, digital pen technology promises to benefit foreign language learning goals such as improving auditory comprehension and pronunciation. Moreover, the ability to dynamically record, replay, and archive audio content as well as the history of interaction that reflects a student's progress provides a new data collection facility for language instruction.

While there are many language-based computer programs for children (i.e., for phones, tablets, and desktop computers), there is a need to explore early learning experiences that might be best supported by paper materials. This paper presents the development and refinement of an end-user toolkit for authoring interactive paper materials. In addition to rapid iterative testing with 10 users, we deployed this toolkit in three contexts with over 70 users from age three to 61. Our data indicate that the toolkit is both easy to use and useful for a variety of language and communication activities.

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¹<http://www.anoto.com>

²<http://www.livescribe.com>

³<http://www.leapfrog.com>

RELATED WORK

Paper is a flexible medium with many affordances not supported by current digital systems [18, 8, 9, 11]. The idea of linking paper documents with a digital system has been investigated in numerous research projects, including Wellner's Digital Desk [24], MacKay's A-Book [10], and the Audio Notebook [21]. More recently, digital pen and paper technology has been explored for scenarios such as document editing [3], linking handwritten and audio notes [2], text processing [23], PowerPoint presentations [19], field and laboratory scientific notebooks [25, 22], and collaborative annotations [20]. Oviatt et al. [15, 13] describe the challenges and opportunities for multimodal digital pen and paper systems.

Commercial versions of digital pen technology enable mainstream use of pen-based systems for education. The Livescribe² pen supports linking handwritten notes with audio content and is marketed as a study aid. LeapFrog developed several versions of a digital pen for language and literacy development, including the Tag (ages 4-8), Tag Junior (age 2-4), and FLY Pentop Computer (age 10-13)³. Several researchers have examined digital pen technology for math learning [14, 5], but relatively little research explores the potential of digital pen technology for a broader class of language development and communication activities.

One challenge is that educational content provided by commercial digital pens (e.g., LeapFrog) is static and not customizable. Several toolkits have been developed to support hybrid paper-digital interaction and to help developers build custom pen and paper applications [26, 4, 12]. Commercial digital pen products by Anoto and Livescribe also have software development toolkits. However, using these toolkits requires programming experience and therefore development of custom applications remains inaccessible to many user groups who may know how to best exploit digital pens.

This paper introduces a general end-user toolkit for authoring interactive paper materials. As with other prototyping toolkits (e.g., [6, 7]), TAP & PLAY enables rapid creation of custom user interfaces. The software allows dynamic linking and re-assigning of various regions of paper with a variety of audio resources. TAP & PLAY is also a physical toolkit in that the system allows facile coupling of digital interactions with a variety of paper and physical materials. TAP & PLAY extends the earlier work of Piper et al. [17] on a toolkit specifically tailored for therapists working with older adults with aphasia. The motivation for an end-user authoring toolkit arose during a year-long field study of speech-language therapy involving older adults with aphasia [16]. We extend this prior work in three ways: (1) we describe the iterative development of a general end-user authoring toolkit, (2) we evaluate and improve the usability of the toolkit through rapid iterative user testing, and (3) we examine the toolkit's generality and flexibility by deploying it in three real-world contexts.

SYSTEM DESIGN

TAP & PLAY is an application that runs on Livescribe digital pens. These pens integrate a processor, memory, and an infrared camera into what appears to be a normal pen. They exploit Anoto's digital pen technology to interpret a

unique dot-pattern printed on standard paper. By decoding the printed pattern, the device can track its exact position on paper in real-time. Unique to the Livescribe pen is a built-in speaker, microphone, and OLED display. TAP & PLAY allows users to create interactive regions on dot-patterned paper and program them with a combination of the three basic interactions supported by Livescribe digital pens: (1) audio recording, (2) audio playback, and (3) handwriting recognition. By exploiting this functionality, TAP & PLAY supports creation of custom multimodal applications for specific user populations. TAP & PLAY is designed for two categories of users: *content authors* who use the digital pen to create a pen and paper application, and *content users* who use the developed materials for their specific needs. Authoring multimodal content with TAP & PLAY is completely paper-based and does not require access to traditional software development environments or a separate computer. Instead, content authors "program" the pen and paper materials using a special paper-based authoring interface we have developed.

Programming Multimodal Interactions

The authoring interface consists of paper-based control panels that enable the creation of multimodal interactive paper regions. Authors can use any kind of Livescribe dot-patterned paper and assign particular interactions to specific regions of a page. Interacting with a paper region with the digital pen can initiate the playback of audio that has been previously recorded or that is stored in the pen's sound library (e.g. animal sounds, traffic noises), can start the recording of the user's speech, or can enable the recognition of their handwriting. Figure 1 shows the TAP & PLAY control panels. Figure 2 illustrates the process of creating an interactive region

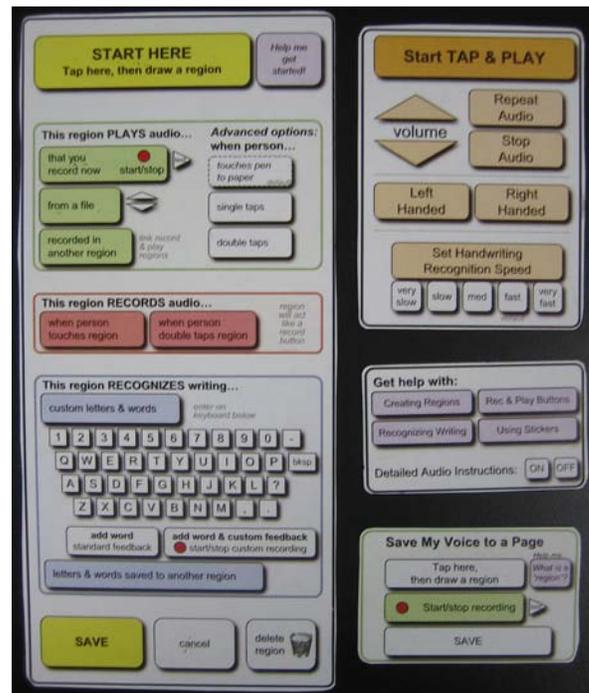


Figure 1. Clockwise from top left: main control panel for authoring, general interface controls, help buttons, and quick custom audio widget.

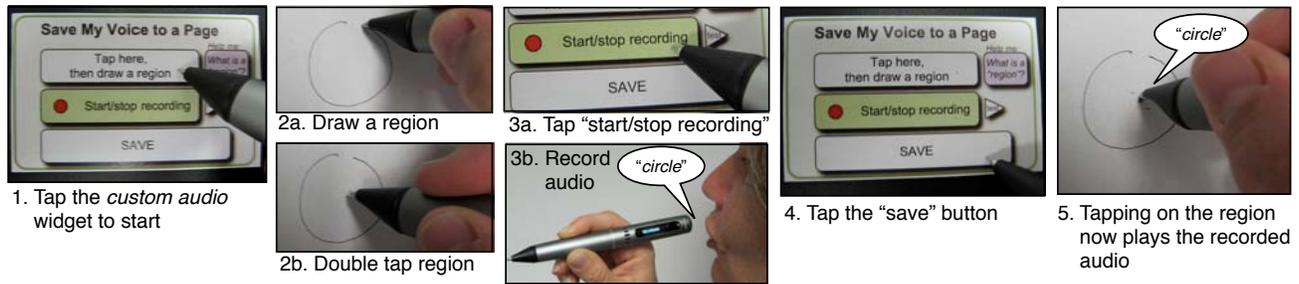


Figure 2. The quick custom audio widget allows users to quickly and easily record speech and save it to any paper with the Livescribe dot pattern.

with the *quick custom audio* widget. Additionally, a panel of help buttons (Fig. 1, right-middle) provide supplementary audio instructions for novice authors, and a general interface controls pen settings such as volume, left- vs. right-handed usage, and handwriting recognition speed (Fig. 1, right-top).

Content authors use the pen to tap on the control panels and TAP & PLAY guides them through the authoring process (experienced authors can disable detailed audio prompts). The largest control panel (Fig. 1, left) is the full-featured interface for authoring materials. This control panel allows authors to create playback regions, record regions, and handwriting recognition regions. After defining a new region by drawing it on paper, the main control panel can be used to add the specific interactions and content.

Interactive regions can be layered on top of each other, with the upper regions redefining a specific subregion with different interactions. Also, layering can be achieved by pen-based interactions. Authors can decide to activate specific interactions on *pen-down* (when the pen touches the paper interface), on *single tap* (when the pen taps the paper and then is lifted) or on *double tap*. Observations of an early toolkit [17] indicate that recording audio and saving it to a page was the most frequently used facility. Based on this, we created the *quick custom audio* widget (Fig. 1, right-bottom; Fig. 2) to enable rapid definition of regions that play back recorded speech.

Paper Materials

One distinctive advantage of paper is that it can be manipulated and shaped in many ways. Thus, since user interfaces developed with TAP & PLAY use traditional paper, they can be cut up and glued or taped together or to other objects. Since we wanted to emphasize this unique affordance, we made available a range of paper-based materials with the Livescribe dot pattern. TAP & PLAY works on standard Livescribe notebooks, printed pages, cardboard, stickers (varying sizes and transparency), magnetic paper, post-it notes, and more (as shown in Fig. 3). Authors can use these materials to create hand-drawn paper-digital applications or can print on top of them as they would do with any other paper material.

RAPID ITERATIVE PROTOTYPE REVIEW

A central design goal for TAP & PLAY is to help novice users, particularly people who do not know how to program, quickly figure out how to use the pen-based interface and begin authoring their own multimodal documents. Because we are designing the system to broaden access to pen and paper

technology, it must therefore be quick and easy to use by people with diverse backgrounds and without requiring technical programming expertise. The questions we addressed during the initial phase of research include:

- Do users without digital pen experience understand the idea of a pen-and-paper-based interface?
- Can users quickly determine how to get started authoring their own paper documents?
- Is the basic functionality of the system (creating play, record, and handwriting recognition regions) easy to use?
- Do the audio and text prompts provide clear and sufficient support for navigating the system?

We conducted iterative prototype testing with 10 users (age 20-61, mean=37.5, stdev=15.4) to address these questions. Each participant used TAP & PLAY individually. We video recorded each evaluation session, noted points of confusion and areas for improvement, and logged all interactions on the pen. None of the users had experience with digital pen technology prior to this study. Participants held diverse occupations, including a lawyer, social worker, therapist, elementary school teacher, medical equipment salesperson, non-profit fundraiser, and university students. Only one of the ten participants had any programming experience.

As part of the rapid iterative prototype review we dynamically made adjustments to the user interface layout, workflow for authoring, and cueing presented via the pen's audio speaker and OLED display. Our goal was to iteratively refine the prototype based on user data to quickly achieve a usable design before beginning evaluation in specific application domains. The flexibility of a paper-based control panel and the software we have developed allowed us to rapidly update the system to

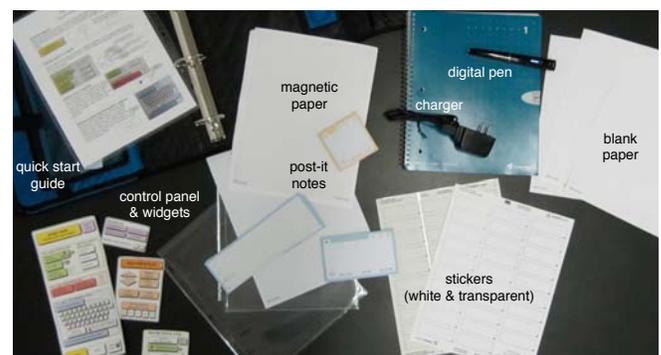


Figure 3. TAP & PLAY material set.

Context of Deployment	Content Designed For	Content Authors	Content Users	Deployment Length
Early childhood education	Young children in classes of 25 (age 3-5)	Teachers & assistant teachers (19)	37 (age 3-5)	11 weeks
Home language activities	Individual children at home (age 3-5)	Parents & grandparents (4)	2 (age 3-4)	6 weeks
Language tutoring	Foreign language students (age 3-65)	Adult instructor (1)	8 (age 3-9)	8 weeks
<i>Total</i>		<i>24</i>	<i>47</i>	

Table 1. Participants involved in field deployment of TAP & PLAY. Content authors created content with TAP & PLAY. Content Users are the groups who used the custom materials created by the authors.

reflect feedback from users. In some testing sessions, updates were made on-the-spot in collaboration with the user. Participants cut up the paper control panel and reconfigured it to reflect their expectations of the workflow. Similarly, researchers and participants collaboratively crossed out and re-labeled buttons and prompts to evolve designs.

Findings and Design Iteration

Getting started was the most salient challenge for users. Some participants (P1-P5) took approximately 20-25 minutes to learn basic functionality of authoring their own interactive paper documents. These users spent at least five minutes trying to understand the idea of authoring interactive paper and how to get started with the toolkit. One initial challenge is that users must first understand interaction with a digital pen, including how the pen detects its position on paper printed with the dot pattern, how to attend to cues provided by the pen's speaker and OLED display, and how to tap the pen on paper-based buttons and widgets. A second challenge is to understand how to program the pen with the paper-based user interface to generate their own interactive documents. Programming with TAP & PLAY is a multistep process with several decision points. Moreover, the idea of "programming" pen and paper to perform specific interactions is an unfamiliar concept. Several users were intimidated by the idea of programming the pen with TAP & PLAY. One participant said, "I can use a regular computer, but this I'm not so good at." Even before starting, at least six participants mentioned that they were not good at this sort of activity.

Partway through the evaluation (after P5), we realized that the key to getting users started quickly and easily is to have them focus first on the *quick custom audio* widget. This presents the idea of authoring interactive paper in a clear and concise way. For participants 6-10, we first showed them the *quick custom audio* widget. These participants rapidly acquired the concept of authoring interactive paper documents and were able to program the pen to perform basic functions within 10 minutes. This finding informs how we introduce the system in the contextual evaluations described below.

We also addressed the challenge of getting started by adding a large "start here" button to direct users' attention to the starting point as well as a "help me get started" audio help button. In addition, we created supplementary paper materials (e.g., a tips and hints page) to support initial learning. One user said, "I'd want a user manual to give me instructions." Another person commented, "It's easy to navigate but you still need something to read like a manual." Throughout the user testing we noted the places where users needed additional audio cueing and iterated our design to provide needed support. The system now provides a setting for detailed versus minimal audio instructions depending on user needs.

We made several design modifications to streamline the authoring process. In an early toolkit version, users were required to enter an "edit mode" to start authoring content. We removed the need for modes and now with four steps (achievable through both the full control panel and the custom audio widget) a user can program the pen to play custom audio when a specific region is tapped. We improved the color-coding and layout of the control panel to enhance readability. Iterative prototype testing allowed us to improve the navigation, layout, workflow, and help facilities provided by TAP & PLAY. The resulting usability of the system is documented below, based on use by more than 70 people in field deployments.

CONTEXTUAL EVALUATIONS

Following the rapid iterative prototype review, we wanted to understand how well the system supports a variety of language activities. We conducted field deployments to address the following questions:

- Are users within different educational contexts (schools, homes) able to integrate the system into their practices?
- Do they use the system in meaningful ways?
- Does the system address important language and communication needs for each user group?

We deployed the TAP & PLAY system with: four groups of early childhood education teachers, two families for home use, and one foreign language instructor. We focused on educational scenarios that involve young children. This complements prior work on digital pens for older adult language rehabilitation [16, 17]. Table 1 summarizes participants. Each group received their own Livescribe pen loaded with TAP & PLAY and a binder with various paper materials printed with the dot pattern (see Fig. 3).

The research team introduced the toolkit to participants and video recorded them learning to use the system. Based on what we learned in our early prototype testing, we introduced the idea of authoring interactive documents by using the *quick custom audio* widget. Our evaluation of the field deployments is primarily qualitative, including field notes detailing system use and the environment, video data of teachers and children using the system, still images capturing the applications end-users created, and interviews describing challenges and opportunities for the system by all people involved. We transcribed interviews and categorized observational data, photos, and video recordings to identify high-level themes. Raw data is presented in quotes whereas our observations and interpretations are reported directly in the text.

Context 1: Early Childhood Education Classrooms

We deployed TAP & PLAY with teachers and teaching assistants (n=19) in four early childhood education classrooms.



Figure 4. Three children (age 4-5) reading interactive books with TAP & PLAY.⁵

Two classes have three to four year old children and the other two classes have four to five year old children. Our research team introduced TAP & PLAY to the four lead teachers in a group setting. The lead teachers then introduced the toolkit to their larger group of assistant teachers.

Adding audio content to books

A basic activity that most teachers created involved programming interactive stickers to read or play sounds associated with parts of a book. Some of the teachers recorded part of the story read aloud or questions about the story and attached the stickers to the corresponding pages of the book. Children independently used the pen to listen to the story (see Fig 4).

Commenting on this activity, one teacher said, “They pick it up so fast, it is incredible. It was really, really easy for them, from the beginning.” She also commented on how the children were fascinated by the pen when it started to interact with them, “The book, you know, asks them questions, and they were responding to the pen. First they looked at me when it started talking, they said, ‘It’s magic!’” She also compared this to her observations of how her students typically read a book, get bored quickly, and want to switch to another activity. She explained, “They wanted to read the same book over and over again, which is really rare. They kept asking, ‘Can I do it again, can I try it again?’ Usually they don’t read the book, they just flip through the pages and whoop it’s over.”

Teachers were pleased by the autonomy that students demonstrated with this activity. This same teacher said, “I really like it. You don’t need an adult to always be there. All I had to say was, ‘so this pen... if you tap on a rectangle, it will talk to you.’ And then I opened a page and asked them, ‘do you see another one?’ And they just right away knew exactly what to do.” She also commented, “I think [this activity] was really successful because they can be by themselves and still learn without someone standing over them the whole time and reading everything.” Another teacher used this approach as an independent reading activity for non-native English speakers. She said, “I have a couple children who don’t speak English fluently. They can just pick up this book, tap on it, and try to follow along with the words, which is another way for them to learn English.”

Linking a child’s speech with books and art

Several teachers mentioned the challenge of capturing and documenting a child’s comments. One teacher said, “It’s hard

⁵All participants (parents on behalf of children) consented to the use of photos for publication.



Figure 5. Teacher asks a child (age 4) questions about a book. He records her answers using an interactive sticker. The student listens to her answers by tapping the stickers in the book.

to write as fast as they are speaking, so sometimes we get close enough but it’s not their exact words.” To solve this problem, teachers in one classroom setup an activity that had children add audio comments to various books and pieces of art. One teacher (see Fig. 5) asked two students (age 3-4) about a book. As they described the contents of a page and answered his questions, he recorded their voices and linked it to the book using interactive stickers. The students were able to independently tap on stickers within the book and listen to their answers.

This teacher said, “You could use just like a regular recorder but you have nothing to attach it to. So this is nice to be able to attach it to the picture directly.” He continued, “The parents like to hear their children talk about the pictures versus us talk to them about their pictures. So it’s nice to be able to hear their children speak about [the pictures].” Several days later another teacher in this classroom also implemented this idea. She had students describe their artwork and recorded their descriptions using TAP & PLAY. She added an interactive sticker to each drawing and observed as the children listened to their narrations (Fig. 6).



Figure 6. Students (age 3) record and replay descriptions of artwork.

Sign language learning

One of the teachers was interested in how TAP & PLAY might support sign language learning. Initially she was skeptical about how well her students (age 4-5) would be able to learn sign language, but knowing about the success of TAP & PLAY in other settings, she decided to give it a try. She used a pre-existing poster showing different letters of the alphabet and the associated signs. She then attached stickers to each letter and recorded the name of the letter, it’s phonetic sound, and an example of a word starting with this letter. By using TAP & PLAY and the interactive sign language poster (Fig. 7) she created, children were able to independently practice the signs for letters of the alphabet.



Figure 7. A student (age 4) practices sign language letters with the help of TAP & PLAY .

The teacher explained that the pen helped in a different way than other tools she has used in the past, such as an alphabet song and a person showing signs for the letters. She said, “They can do it on their own, they can go back, you know. With the song it just keeps going.” She continued, “There are books, but the meaning of the sign is written and they still can’t read.” Finally, she mentioned ideas for expanding this activity, “You don’t have to do just the alphabet, you can do it also with actual signs and kind of teach them little sentences.” A similar activity was created by another teacher. She printed words and signs on dot pattern paper and then recorded the spoken meaning. Children could use these word cards as reference when writing or rearrange them to create interactive sentences.

English-Spanish dictionary

In several of the classes, Spanish is taught on a regular basis. One of the Spanish teachers decided to use TAP & PLAY as part of her daily Spanish activity. Most of the children using TAP & PLAY (age 3-4) already had Spanish in the past as part of the school curriculum, and they have been exposed to basic vocabulary (e.g., animals, vehicles, colors, and clothes). The teacher wanted to consolidate the words she was teaching them to create a stronger connection between the English and Spanish words. She used blank letter-sized Livescribe pages and cut-outs from old books to create an interactive and multimodal English-Spanish dictionary for the children (Fig. 8). Each page contained images of objects beginning with a certain letter in English. The teacher wrote the English and Spanish name next to each image. Tapping on the words written in English or Spanish plays that word aloud.

Children primarily interacted with the application in small groups of two or three, sometimes with the supervision of the teacher, sometimes by themselves. They used the pen naturally, continuously switching between English and Spanish, and often repeating words aloud after listening to the pen’s recording. When asked about the Spanish translation of a particular word, they instantly tapped the pen on the correct translation. One child who was not participating in the session grabbed a *normal* pen from the table and started to tap on objects and on the patterned pages expecting it to work as the TAP & PLAY pen. The children used the digital pen and materials in a playful, game-like manner. The activity appeared fun for the children, as many smiled and laughed as they used the interactive dictionary.

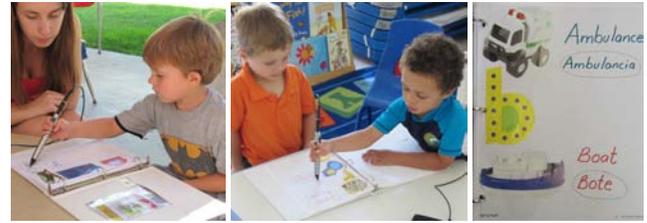


Figure 8. Spanish-English class with TAP & PLAY. Children are interacting with the pen supervised by a teacher (left) or by themselves (center). Right: an example of one page of the English-Spanish dictionary.

The Spanish teacher was pleased by how the children took to this activity. She commented on one student, “She was so into the pen. She was repeating every single word. This is rare.” In general, children liked the pen because “it is fun” and “it makes sound.” One of them said, “It’s cool. When it stops for a long time, I’ll make it go again.” TAP & PLAY was also able to keep the children focused on the Spanish activity for longer than usual. The teacher commented, “You can see the attention span... Some of the children really have a hard time staying focused, and this helps.” She continued, “Usually we just tell them a story, spelling one word first in English and then in Spanish, so they can relate. TAP & PLAY allowed us to continue working in the same way, having them relate the Spanish with the English directly.”

Context 2: Home Language Activities

With two of the children from the Early Child Education Center, we followed up on the usage of TAP & PLAY in a home setting with their parents and grandparents. Both children speak multiple languages; English and Spanish at school and one or more other languages at home. After observing the use of TAP & PLAY for foreign language learning in school, we decided to explore how the toolkit might support language activities at home.

Audio Memory

One of the two children (age 4) is bilingual (English and Italian) and sometimes has difficulties spelling words in the two languages due to different vowel pronunciation. For example, the letter ‘a’ is often pronounced *æ* in English and *a* in Italian, while the letter ‘e’ is pronounced *i* in English and *ε* in Italian⁶, causing some confusion.

In order to introduce new words and work on their pronunciation in Italian, the grandmother (age 61) created an audio version of a well-known memory game (see Fig. 9). She prepared a set of interactive cards using cardboard paper imprinted with the Livescribe pattern on one side and a sticker on the other side. The grandmother recorded pairs of cards as follows: one card plays an animal sound (from the library of pre-recorded sounds that came with TAP & PLAY), while the other card plays a question such as “I am a dog. What sound do I make?” The child tapped the pen on different cards to find pairs. After finding a match, the child turned over the cards and listened to the pronunciation of the word. The grandmother asked her to repeat the word and find two other words that started with the same letter from the set of picture cards that she prepared (Fig. 9, right).

⁶Using the standard International Phonetic Alphabet (IPA).



Figure 9. *Left*: four-year-old child playing “Audio Memory” with her grandmother. *Right*: interactive cards used as part of the game.

The activity was challenging at first. An audio-only memory game that does not have pictorial cues resulted in a much more difficult activity than the grandmother anticipated. “Since they are plain paper cards, I could separate the questions on the right and the animal sounds on the left, and easily change the rules of the game, since it was too difficult for her,” she commented, “but she did great and she could easily use the pen to listen multiple times to the recorded content.” The grandmother explained her ideas for evolving this activity: “Instead of having me listening to her pronunciation and checking if she found the right words directly with her, in the future I could add a *record button* and have her record this by herself, without needing my presence during the game, but only afterwards to check the answers.”

Interactive home games

The second family was a multi-ethnic family living in the United States but with roots in Italy, France, and Portugal. Their daughter has contact with family members all over the world and is therefore exposed to many different languages (two at school plus three at home). The parents created a set of games exploring different aspects of language and geography. They created three distinct games, by exploiting existing materials and attaching stickers, or by using the provided Livescribe notebook in combination with paper materials that



Figure 10. Interactive home games. *Top*: the child (age 3) playing the *spell by listening* game (left) and the *family map* game (right) with her mother. *Bottom*: a collection of games created with TAP & PLAY.

they cut from a book. Figure 10 shows the materials they created and the child playing two of the games with her mother.

The parents first augmented an existing game that involved dice with letters on each face paired with a set of cards showing objects and their spelling in English (see Fig. 10, top-left). With only the object on the card visible, children had to arrange the dice to spell the word on the card. On the sides of the dice, the parents attached a sticker and recorded the sound of each letter. The daughter used the pen to explore letter sounds and arrange the dice into words. When she wanted to check her spelling, she could tap on a sticker on the card and listen to the word read and spelled aloud.

The second activity (Fig. 10, top-right) involved finding the location of different friends and family members on a world map. The parents prepared interactive arrows by cutting up Livescribe sticky paper and attaching it to different locations on the map. For each arrow, the parents recorded the names of people living in that place. The daughter tapped on the arrows and listened to the recording to find out who lived where.

The family also used the Livescribe notebook to create a picture-audio trivia game, in which they could ask a question such as, “I am warm and bright, I come in the morning and go at night. Who am I?” The daughter listened to the prompt and then selected one of four images. She was able to check her answer by tapping the sticker that was attached to the image (Fig. 10, bottom).

The parents commented on their daughter’s interest in the games. The father said, “She was much more engaged. She saw that she had a voice and there was an opportunity for her to actually give the answer. She felt like she was on her own in front of the game.” He also mentioned, “Normally, if we are there she wants us to help. Instead here was the pen that was helping, so that allowed her to be more independent.” While the child responded well to all of the games, the father commented on the map game in particular: “This was an absolute success for her, and we really enjoyed it... She liked the fact that the map was big. She could locate where the people were very easily.” In terms of learning, her father said, “It was amazing how excited she was to discover friends and family in different places by listening to their names. She really made the connection between the location and the people living there, and this is because of the link between the image and the audio.”

Finally, the father stressed the range of activities that TAP & PLAY supports: “Possibilities are countless, there is no limit apart of your own imagination. With other educational toys like the LeapFrog ones... you can’t change the games.” He said, “With TAP & PLAY you spend time planning and you think about how the child is going to react. You also tailor it to the specific likes of the child. It is really good for both the child and the parent, for establishing the link between the two. In the end you spend more time together.”

Context 3: Supporting Foreign Language Learning

To further understand the potential of TAP & PLAY to aid foreign language learning, we deployed the toolkit with an Italian language teacher who works with students (age 3-65)

learning the language to communicate with distant family members or to be able to read and speak while traveling. Teaching activities are typically structured as individual tutoring sessions or as interactive group sessions in which students participate in a specific activity together, sometimes taking turns, or in group conversations. The instructor explored the use of TAP & PLAY in these different contexts.

Learning language through songs

The instructor uses song as a vehicle for foreign language instruction. As part of a summer language camp for children (age 3-7), she created a set of eight posters, each representing a verse of a well-know Italian song. Using TAP & PLAY, she recorded each verse of the song, programmed clear stickers to play the verses, and attached the stickers to the paper posters (see Fig. 11). The instructor also created stickers for keywords and attached them to specific locations that were purposely left blank. On each poster, interacting with the main sticker plays the verse associated with it, while tapping the sticker on top of a blank space plays the missing word.

We observed the Italian instructor using these interactive posters during her summer language camp. She demonstrated how to use the pen and the children immediately asked to try it on their own. For this group activity, the instructor asked the students to say the vocabulary word that was missing in each sentence. The student who answered correctly got to use the pen to tap on the poster and check their answer. The novelty of the digital pen and chance to use it in front of their peers was motivating for the students. The instructor explained, “I was surprised myself how TAP & PLAY can be easily used and how it fascinated the kids. They really wanted to use the pen. I was not prepared for this. Usually I have to ask them to do something or to answer my questions, but with this, they wanted to make the paper talk by themselves.”

Group word learning

After observing the kids’ excited use of the pen with posters, the instructor spontaneously created another group activity. Working on the floor with children around her, she drew a tree and different fruit on a piece of paper. Students took turns recording the names of various fruits in Italian. Surprisingly, one of the students (age 7) was able to independently use the



Figure 11. Italian instructor created interactive posters that play parts of a song and key vocabulary words.

quick custom audio widget to add her voice to a drawing on paper. Reflecting on how the student could easily use the pen, the instructor commented, “It is a wonderful tool for the children to explore and invent something new by themselves. They can start from a point that I created and end in something different that we created together.”

TAP & PLAY worked well for the Italian instructor’s needs. “This pen facilitates my work a lot. I can apply it directly to something I already create on paper,” she said. The ability to make existing materials interactive by using dot pattern stickers was particularly useful. She explained, “Instead of using an external recorder that I have to start and stop, moving off the focus of the class... I am able to work easily by just touching some areas. The connection is much stronger.” Finally, she emphasized the importance of the pen’s portability, “You can take it out of the classroom too... You can be anywhere and just use this very simple, but powerful tool.”

Targeting Language Development Outcomes

At the end of the study, we surveyed eight educators involved in this project about how well TAP & PLAY supports developmental goals for young children. Since most activities were designed for children under age five, we evaluated how well TAP & PLAY supports the goals described within the California Preschool Learning Foundations [1] (also used by the classes in our study). Participants rated 48 areas of development (covering self, reading, writing, speaking, and mathematics). Table 2 lists the top 12 areas of development that are best supported by TAP & PLAY.

Developmental Goal	Mean	Stdev
Vocabulary in listening	4.88	0.35
Vocabulary in speech	4.88	0.35
Use language to create oral narratives about personal experiences	4.88	0.35
Sound differences in the home language and English	4.88	0.35
Phonological awareness when reading	4.75	0.46
Alphabets and word/print recognition	4.75	0.46
Participate in read-aloud activity	4.75	0.46
Demonstrate awareness that print carries meaning	4.75	0.46
Writing strategies (grasping and using different drawing/writing tools)	4.71	0.49
Understand story structure	4.71	0.49
Show an increasing understanding of book reading experience	4.64	0.48
Positive group participation	4.63	0.52

Table 2. Participant ratings for top 12 areas of development supported by TAP & PLAY. Scores are from a five-point Likert scale, 1=“does not support at all” and 5=“supports extremely well”.

DISCUSSION

Early childhood education teachers, language instructors, parents, and grandparents quickly implemented new interactive paper activities. During these field deployments we observed the development of a variety of digital pen applications: adding audio content to books, linking audio narrations directly to children’s artwork, learning sign language, a multimodal English-Spanish dictionary, multi-lingual games for home use, and “singing posters” for children in a summer language camp. In this section, we summarize key findings from the present study and plans for future work.

Linking Audio with Paper

TAP & PLAY demonstrates an effective approach for linking audio content with a variety of paper materials. The toolkit allows facile coupling of rich audio information with many forms of paper-based content. We reported on novel applications of multimodal paper-digital interfaces in three contexts, but the approach has the potential to support many activities related to language development, speech rehabilitation, audio archiving, and supporting recall or reminiscence.

Integration with Physical Objects

Often the limitation of digital pen and paper publishing architectures is that they require specialized software and a printer to print the unique dot pattern. TAP & PLAY not only enables easy linking of audio with paper materials but also allows integration with physical objects through stickers printed with the dot pattern. This simple extension yields a powerful approach that was (1) the most frequently used part of the material set and (2) the key component of enabling a new class of multimodal language activities. Interactive stickers allowed users to naturally integrate multimodal content with physical objects, including dice, maps, books, and posters.

Supporting Existing Work Practices

The user groups we studied have highly specialized practices involving paper-based content. Classrooms are filled with paper labels, posters, instruction sheets, and more. Additionally, children have established practices that involve specialized paper interfaces such as reading from hardback books, writing on lined paper, and creating art projects with construction paper and glue. Our toolkit, along with the introduction of interactive stickers, allowed content authors to build on their current practices and supplement existing materials by adding audio content. The unique ability of TAP & PLAY to support these practices and the use of pre-existing paper content is a central reason for its success.

Learning Pen and Paper Authoring

At the outset of this study, it was unknown how well end-users would understand and carry out their own “programming” of paper-digital materials. We found through early usability testing that teaching pen-and-paper programming through the custom audio widget is a useful didactic approach. This widget simplifies the complex concept of dynamically creating references between dot pattern space and audio content. An important property of our toolkit is its paper-based authoring interface; the interface may be cut up (or even ripped), menu items can be relabeled or amended, and the entire UI can be reconfigured to fit the needs of each individual user. This stands in sharp contrast to purely digital authoring tools.

A Natural Interface for Children

During the course of the study, we observed how digital pens and TAP & PLAY materials moved from the hands of content authors (teachers, parents, and grandparents) to the hands of children. The vast majority of adults authoring materials showed some initial reluctance in having children use the pen, and several asked what would happen if a child broke the pen. It also seemed that many adults initially thought that the digital pen was a complex tool that would be too difficult for children to manage. On the contrary, children used TAP & PLAY

without fail, easily holding the pen and tapping on interactive materials. Even though a pen is usually a writing device, it is a natural device for tapping and selecting interactive regions on paper. When asked what he normally uses a pen for, one student (age 3) answered, “for tapping.” Another (age 5) commented while using the pen, “You just tap here and it plays.” We observed the ease with which children recorded their voice with the pen. One child (age 7) even created her own interactive region with the control panel.

Independent and Collaborative Use

Participants commented on the potential of TAP & PLAY to support independent work. Several teachers reported that TAP & PLAY kept the children focused on the activity much longer than other approaches. One teacher stated, “I was surprised by how interactive they were. They were asking and responding, and they wanted to do it like five times for the same book.” She also said, “They didn’t even need us there... As soon as they heard the question, which means that they’re really listening, they would respond with the correct answer.” In each setting we also observed collaborative use of the system, and in many cases collaborative authoring of content. This was particularly evident in the Italian language summer camp. As another example, a teacher worked with three students to create a story. He drew with the digital pen and the children collaboratively narrated the story.

Limitations and Future Work

Participants wanted to share materials with others and to be able to transfer information between digital pens. Currently sharing between pens is not possible, although we are building a solution that allows sharing of custom materials. In addition, for this study, we printed all materials and distributed them to participants. We envision a web interface that would enable participants to print their own paper materials with the dot pattern on a centralized printer. Each group who participated in the contextual deployment only received one pen (i.e., one pen per classroom). This limited the types of activities that were possible. Exploring the use of multiple pens and providing facilities to share information between pens are important next steps in this research. We described how users in different contexts began to integrate this system into their practices and how the content they created was used by children. While the results of these initial deployments are very promising, we plan more formal evaluations in the future.

This paper primarily describes language learning activities for children, but we are also exploring use of the TAP & PLAY system for other populations. For example, digital pens are an appropriate pointing device for older adults with limited dexterity [16]. Another area of interest involves children with special needs. Since the inception of TAP & PLAY, several parents and relatives of children with autism have requested access to the system. We see potential for this type of flexible, paper-based system to support language development and therapy activities involving a wide range of populations. We plan to further develop and explore TAP & PLAY in a wide range of domains to assess its generality for authoring multimodal materials.

CONCLUSION

This paper presents the development of an end-user toolkit for authoring custom paper-digital materials. We examine the usability and utility of this toolkit for novice, non-technical users. An important contribution of this work is a long-term field deployment of the TAP & PLAY authoring system involving over 70 adults and children in language learning contexts. This allowed us to study how educators and parents incorporate digital pen technology into their daily activities, and in turn, we identified ways in which TAP & PLAY might be improved to support literacy development and language instruction. By empowering end-users as content authors, we observed novel and innovative uses of digital pen technology for language-related activities.

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