Developing Intelligent Sketch-Based Applications to Support Children’s Self-regulation and School Readiness

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ABSTRACT
Abilities for fine motor control and executive attention are aspects of self-regulation that contribute to children’s school readiness and achievement, and can be taught and improved through sketching and writing activities. Recent interactive sketching applications have emerged to assist children in developing self-regulation skills through playful learning interfaces. Existing applications tend to focus on rote-based activities where children trace over shapes with little to no feedback for children to self-regulate their learning and monitor their improvements. In this paper, we present our initial child-centered intelligent sketching user interface prototype called EasySketch, designed to support children’s development of self-regulation skills, particularly fine motor, accuracy, and attention-related skills. Our prototype improves upon existing applications by providing immediate evaluation and constructive feedback for self-regulated learning of sketching and writing skills. In the process of evaluating and providing feedback to improve self-regulation, our sketch-based application teaches children pre-reading and pre-math skills such as writing digits and letters.

Author Keywords
Children-computer interaction; self-regulation; fine motor skills; sketch recognition; intelligent user interfaces; school readiness.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
In order for children to successfully participate in and learn from everyday school activities, they need self-regulation skills [18]. While behavioral self-regulation consists of both gross and fine motor control, fine motor control along with executive attention skills (skills needed to complete tasks and goals even in the face of distractions or competing interests [4]) may be more important for mastering basic skills required in the classroom such as learning to write and draw [16]. For example, young children are often expected to start drawing with crayons or markers and writing with pencils, all of which require fine motor and executive attention skills [17]. In preschool children, the abilities for fine motor control and executive attention predict adaptive skills, including adaptability, social and communication skills, leadership skills, and study skills [17]. A variety of methods and procedures have been developed and validated to assess children’s self-regulation skills, including fine motor control and executive attention. For example, Kochanska and colleagues developed and validated a battery of assessments for behavioral self-regulation [15, 20]. Several of the assessments focus on fine motor control, requiring children to trace geometric figures such as a star or a circle using a pencil as slowly as possible without going outside the designated lines of the figures. To complete such a task with accuracy, children must demonstrate fine motor inhibitory control and executive attention (i.e., paying attention and following instructions of not tracing outside the lines). Studies have found that children’s performances on such tracing or drawing assessments predict developmental and academic outcomes [16, 17]. Given the link between behavioral self-regulation and positive developmental and academic outcomes, efforts to improve children’s fine motor control and executive attention through drawing or sketch-based activities may have positive influences on learning and academic outcomes.

With technological advancements of pen- and touch-based computing devices, development of intelligent sketch-based applications appropriate for use by young children has the potential to impact children’s development of self-regulation and enhance their school readiness and learning. In addition, development of child-friendly sketch-based applications has the potential to actively engage children in their learning while allowing educators or parents a systematic method of tracking children’s developmental progress in their behavioral self-regulation over time. The continued mainstream popularity of mobile devices such as smartphones and tablets is also encouraging developers to create mobile apps that are fun and engaging for young users. A major shortcoming of existing applications is that they are rarely informed by child development and learning theories and research, and include overly simplistic fine motor skill exercises along with limited binary feedback of whether children’s drawings are correct or wrong.
In this paper, we propose developing applications with intelligent sketch-based user interfaces on touch- and pen-enabled computing devices, with focus on complementing traditional educational approaches and improving children’s applications in regards to development of fine motor skills. We designed our preliminary children’s sketching application EasySketch to enable children to better develop their fine motor skills of sketching and writing. Our application first aims to provide children with better playful learning activities through less restrictive sketching exercises. We additionally designed our application to provide caregivers with more valuable automated assessment and recognition information of children’s fine motor skill development.

RELATED WORK

Children’s Learning Process

Children’s learning process has been studied extensively in educational psychology field [4, 15, 16, 17, 18, 20]. For example, Piaget believed that children are active participants in learning [11]. He viewed children as busy, motivated explorers whose thinking developed as they acted directly on the environment using their eyes, ears, and hands. According to Piaget, between infancy and adolescence children move through four stages of cognitive development (Table 1). Along with the cognitive development, Piaget also described that sensory and motor experiences are the basis for all intellectual functioning [9]. As a result, fine motor skills have important role in children’s learning process.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Age</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensorimotor</td>
<td>0-2</td>
<td>Begin to make memory</td>
</tr>
<tr>
<td>Preoperational</td>
<td>2-7</td>
<td>Gradually develop language, Ability to think symbolic form</td>
</tr>
<tr>
<td>Concrete operational</td>
<td>7-11</td>
<td>Able to solve concrete problem in logical fashion</td>
</tr>
<tr>
<td>Formal operational</td>
<td>11-adult</td>
<td>Able to solve abstract problem on logical fashion</td>
</tr>
</tbody>
</table>

Children’s Apps

To enhance children’s fine motor skills, many applications provide learning material that allows preschoolers to develop their fine motor skills through drawing. The applications help the children’s readiness for kindergarten. The first example is “Create & Learn” by Fisher-Price, which runs on iPad or iPhone. This application provides a sketchpad, which looks like a sketch board, and children can draw on the board (Figure 1).

Another example is “Dextra Jr.” by BinaryLabs. The application has many activities through which children can practice their fine motor skills by drawing. For example, Figure 2 and 3 show activities that children can follow the instructions to find a “Star” and make a letter “P”.

As a result, these applications provide activities that encourage children to enhance their fine motor skills by drawing, but can only hope that these practices actually enhance their fine motor skills. Unfortunately, these applications do not recognize children’s fine motor skill levels automatically, but only include simple fine motor skill activities which cannot describe whether preschoolers’ fine motor skills reach a more mature level, like those of grade schoolers. To recognize children’s fine motor skills, our application includes a fine motor skill classifier [14] that determines sketchers’ fine motor skills as “mature” or “developmental” from shape drawings via digital pen.

Another deficiency of these related applications is that they have limited binary feedback that only checks whether their traces are correct or incorrect. So, the applications can not tell what “shape” the children drew. To teach children how to draw digits/letters better, our application includes a shape recognizer [23] that can recognize the children’s shape drawings.

Children’s Gesture Interaction

Previous work has examined the drawing behavior differences between children and adults via pen- and touch-based apps [1, 13]. Their hypothesis is that children’s weaker fine motor skill control will make the difference. Anthony et al. focused on children’s touch-based gestures (drawing and pointing) [1]. The researchers collected touch-based sketch data from sixteen children (ages 7-16) and fourteen adults from mobile devices and tested sketch-recognition accuracy via two state-of-the-art recognizers (i.e., $N$ recognizer [2]...
and Microsoft Tablet PC recognizer). Finally, they found that the both recognizers work better on adults’ drawings rather than children’s drawings [2].

Then, Anthony et al. asked adults and children to target objects of varied sizes and distinct locations on screen. The researchers reported that the adult participants performed better in touching the on-screen targets than child participants. As a result, children could not target small shapes as well as adults. However, the limitation of this study is that the ages of the child users are varied (age 7-16). As we can see from Table 1, the age range does not represent children’s fine motor skill ability well. The participants should be divided into more subgroups. Additionally, the researchers are missing preschoolers (younger than age 7). So, we cannot assess the fine motor skill ability of preschoolers by this work [1].

Kim [13] focused on pen-based drawing behavior between preschoolers (age 3-4), grade schoolers (age 7), and adults (graduate students). The researcher collected the drawing data from a sketch-based educational application (Figure 4) that teaches children how to draw digits (0-9) /letters (A-F) via pen-based tablet PC. From the data, this study compared the drawing speeds and size differences across age groups and found that adults drew the shapes fastest, preschoolers were the middle, and grade schoolers drew the shapes slowest. Kim also compared the drawing size, and found that adults drew the shapes largest, grade schoolers were the middle, and preschoolers drew the shapes smallest. However, the application only checks the correctness of the drawn shape as compared to a template, so it does not tell us about children’s fine motor skill ability.

IMPLEMENTATION
As a result of the limitations from the current applications that teach fine motor skill development to children, we implemented an intelligent user interface, EasySketch that determines children’s fine motor skills automatically from the children’s sketches. The application teaches children how to draw digits (0-9) and letters (A-F) and returns feedback as children’s fine motor skill progresses ("mature" or “developmental”).

Case Scenario
The target users for our EasySketch system are preschoolers those who are still developing their fine motor skills and preparing to go to kindergarten (typically age 5-6 in United States). Our target user group can also include children who are already attending kindergarten, but still have less fine motor skill ability than their peers. In this section, we describe a representative case scenario with our target users below. Figure 5 illustrates our scenario.

• Step 1: A child sits with a pen-capable tablet placed on a table while holding a digital stylus, and their parent sits next to the child.

• Step 2: A child practices shapes with the pen-capable tablet with the digital stylus. This practice will make the child feel comfortable with the device and application. If the child is already familiar with the tablet and application, the child can skip this step.

• Step 3: The child draws digits (i.e., 0-9) and letters (i.e., A-F) on the tablet with the digital stylus. The parent does not provide any instruction on how to draw the shapes, instead the parent provides information on what the child has to draw if the child does not know. Whenever the child draws the shapes and clicks the checkmark button in the application, the application recognizes child’s fine motor skill from feedback provided by the fine motor skill recognizer. If our application recognizes child’s fine motor skill as “developmental”, the application returns output such as, “Yay! You are learning!” The child can develop their fine motor skill repeating steps 1-3 until the child has reasonable fine motor skill.

• Step 4: If the application determines the sketching skill as mature level, then the application returns output such as “You mastered that shape!”.

• Step 5: The application displays how many times the child drew the shapes correctly for each drawn shape.
Designing Application for Children

Our target users are preschoolers and kindergarteners, who are still developing their fine motor skills (under age 7). Designing applications for these age groups has major challenges. Difficulties includes:

- **Less Cognitive Skill.** As described in Table 1, preschoolers have less cognitive skill than grade schoolers and adults. This requires our application to be easy enough to use.

- **Less Knowledge.** Preschoolers are still learning basic shapes. So, they may not know how to draw the digits and letters. Our application includes animated image files, which show how to draw shapes of digits and letters. Different people draw the same shapes differently, and the differences are noticeable between right- and left-handed people. Because there is no standard way to draw shapes, one of our authors made the drawing instructions. However, we did not restrict children to follow these animated instructions, but they could follow the instructions if they did not know how to draw those shapes. Also, our recognizer could determine the child’s shapes regardless of their various drawing styles [13, 14].

- **Easy to Lose Interest.** As Druin described in [5], preschoolers notice “what is cool, how easy things are to learn, what things look like” and “how much multimedia there is in a product”. Therefore, our application includes textual and audio feedback that are specifically catered to children. For example, if our fine motor skill classifier determines a child’s drawing as “developmental”, then the application shows text feedback such as, “Yay! You are learning”, while simultaneously playing an audio cue corresponding to that result.

Interface

Figure 6 explains the interface of our application. The application includes five panels as follows:

- **Question Panel.** Prompts to the child on the shape to draw.

- **Instruction Panel.** Displays an animated image of the sample shape and instructions on how to draw that shape.

- **Editing Panel.** Allows the child to edit their drawings, which includes five editing activities: erase, save, go to next question, replay, and check the answer.

- **Feedback Panel.** Displays the text feedback.

- **Sketch Panel.** Allows the child to draw sketches.

After the child finishes drawing the sixteen shapes (0-9 and A-F), EasySketch shows a total summary of the child’s sketch recognition accuracy score and correctness of each of the sixteen shapes. From this information, parents/teachers can assess what shapes specifically the child has difficulty drawing. Also, they can check the child’s drawing behavior by clicking the “replay button” in the editing panel in Figure 9. From the information, the parents/teachers can know how their children are drawing the shapes and assess the children’s drawing ability.

Recognizers

To recognize fine motor skills and shapes drawn by users, EasySketch implements a fine motor skill classifier: KimCHI (Kim Computer-Human Interaction) [14] and a shape recognizer: a modified version of the Valentine Recognizer [23]. Figure 7 shows an overview of our recognition and classification architecture.

Whenever the user draws a shape, KimCHI determines the user’s fine motor skill ability as “mature” or “developmental” using selected feature sets such as direction change ratio from 130 sketch features (e.g., [7, 10, 19, 21, 22]) and a classifier (Random forest + Bagging) [14]. From the previous study [14], we found that grade schoolers and adults (those who have mature fine motor skill abilities) can draw curved...
shapes, such as the digit “3”, better than preschoolers (those who have less fine motor skill ability). So, checking if the children draw curve shapes well can determine their fine motor skills.

Valentine recognizer determines the shape intended by a user’s drawings using a template-matching method. Our modified version of Valentine Recognizer calculates the Tanimoto Coefficient originally described in [12] between one template shape (whose shape definition is known) and one user shape (whose shape definition is unknown) [23]. The template shape that generates the largest Tanimoto Coefficient is chosen as the closest match, our recognizer assigns its shape definition to the user’s shape.

EVALUATION
While we have completed pilot studies with adult and child users, we have not begun testing our application with children. In this section we present and discuss results from the previous studies on how well our motor skill classifier and our shape recognizer worked [14]. In addition, we present pilot data on parents’ evaluation and feedback regarding the usability of our interface with young children.

Fine Motor Skill Classifier Evaluation
To make our fine motor skill classifier, we recruited a total of twenty four participants consisting of twenty children and four adults, where the latter were graduate engineering students (Table 2). Since children’s learning skills are different by their age as described in Table 1, we categorized the children into two different groups: preschoolers and grade schoolers. We also conducted the data collection on the adults separately from the children: the adults provided data in a research lab environment, and the children provided data in more familiar environments (e.g., home, church) while accompanied by their parents. In order to ensure that children produced natural sketches in our data collection, we requested that parents not assist their children during sketching.

Table 2. Basic demographics of participants in the user study.

<table>
<thead>
<tr>
<th>Group</th>
<th>Adults</th>
<th>7-8 year-olds</th>
<th>3-4 year-olds</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td># of volunteers</td>
<td>4</td>
<td>12</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td># of sketches</td>
<td>320</td>
<td>227</td>
<td>178</td>
<td>725</td>
</tr>
</tbody>
</table>

For the data collection, we provided two different procedures to the participants. For the adult and grade schooler participants, we asked them to draw each digit (i.e., 0 through 9) and letter (i.e., A through F) exactly twice. For the preschoolers, we asked them to draw a reduced testing set of each digit (i.e., 0 through 9) and letter (i.e., A through D) only once. Each participant was allowed to draw each shape naturally, without restriction to drawing preference such as stroke order. The participants were also informed that they could stop drawing at any time, but everyone successfully completed their drawings. Since our data collection involved child participants, we limited the time duration for the children for up to forty-five minutes as suggested by Hanna et al. [8]. All participants were able to complete the data collection within twenty minutes using a Panasonic Touchbook and corresponding digital stylus.

Using the data from the above-described experiment, we trained and evaluated our fine motor skill classifier. Our hypothesis was that grade schoolers and adults will have better fine motor skill ability than preschoolers. So, we distinguished sketches of preschoolers and more mature sketches (grade schoolers and adults).

As a result, our classifier was able to automatically distinguish preschoolers (ages 3-4) and grade schoolers (ages 7-8) with a precision of .83, recall of .828, p-value of 0.001, and an f-measure of .827 with 10-fold cross-validation. When distinguishing between preschool (ages 3-4) and more mature sketchers (combining children and adults), we got a precision of .909, recall of .909, p-value of 0.001, and an f-measure of .904 with 10-fold cross-validation. More details can be found at [14].

Shape Recognizer Evaluation
We have evaluated our shape recognizer [23] with a total of fourteen participants including three preschoolers (age 3-4), seven grade schoolers (age 7), and four adults (graduate students) [13]. We collected the data with the same procedure with the previous section. We defined recognition accuracy as the ratio of the correctly recognized drawings of an age group to the total number of drawings of that age group. Finally, our recognizer could determine adults’ drawings with 90.0%, grade schoolers’ drawings with 83.75%, and preschoolers’ drawings with 34.4% accuracy. Our recognizer worked well for adults and grade schoolers, but worked poorly on preschooler’s drawings. The most prominent reasons are their lack of domain knowledge (Figure 8). Even though we provided instructions how to draw shapes, preschoolers had difficulty drawing the shapes. We hypothesize that the difficulty was caused by their lesser-developed cognitive and fine motor skills. More details about drawing behavior and recognition accuracy differences between children and adults can be found in [13].
Interface
We evaluated our interface (Figure 6) during the development process to know about the usability of our interface. We recruited three parents who have children (preschoolers) and asked them to draw digits (0-9) and letters (A-F). Finally, we provided questionnaires that inquired about: the ease of use of the interface and the usefulness of feedback and materials. We got mostly positive feedback from the parents. They liked the idea that our interface can identify the level of children’s fine motor skills. They also liked the learning materials that show instructions how to draw digits/letters and that our sound feedback will be interesting to children. However, they recommended us to replace the digital pen with one large enough to be gripped easily by their children’s small hands.

FUTURE WORK
From the pilot study, we have found that parents liked the interface of our application. However, usability tests with children along with focus groups on their preferences in sketch-enabled applications still need to be conducted. Importantly, we need to test how well our application recognizes children’s writings and drawings and then evaluates and provides feedback on their fine motor skills. The following section will describe our evaluation plan.

Participants
Our goal is to recruit participants from two different groups for different perspectives of the software.

- Children: who are still developing their fine motor skills and preparing for kindergarten.

- Teachers/Parents: will offer the instructions of contents if the children do not understand what they have to draw.

Location Conditions
There is greater flexibility in evaluating participants based on location, since our system is not restricted in use to only classroom environments. We desire that our system be available outside the classroom as well to provide more opportunities for children to learn and optionally with accompaniment from their parents. But for the sake of the case scenario and to better convenience us in evaluating our system’s performance, we would like to focus our attention of location to a classroom environment with the presence of the teacher for the physical instruction of the lesson and the presence of the children’s parents for the physical usage of the system.

Interface Comparison Test
To understand the preference of the interface of EasySketch, we are planning to have a A/B test for comparing our application with another application (“Create & Learn” [6] or “Dexterity Jr.” [3]) which we will call a control application. A team will consist of a child and a parent/teacher. They will not have any experience with our application or the control application. When we have enough teams, we will divide them into two groups. One group will test our application followed by the control application, while the other group will test the applications in the opposite order. They will draw the letters (A-F) using both applications. After they finish their drawings, we will ask the following questions through questionnaire and/or interviews with children and parents/teachers.

- “Which application do you prefer?”
- “Why do you prefer that application?”
- “Was the fine motor skill feedback from our application understandable?”
- “Were the learning materials in those applications easy for children? If it was not, please tell us your recommended learning materials.”

After the feedback from our participants, we will improve our application to properly help children develop their fine motor skills.

Test Fine Motor Skill Classification Result
From the logged data from our application, we will check whether our application correctly recognized their fine motor skills with educational psychologists. The educational psychologists will assess children’s fine motor skills with paper and pencil. After that, we will check the correlation of our application’s fine motor skill results with the data from educational psychologists.

Additionally, we are planning to include verbal instructions that read questions (what they have to draw). Preschoolers are not likely able to read questions. Including verbal instructions will be beneficial to preschoolers using our application.

Finally, we plan to make our interface more childish and extend it to the Android platform. Figure 9 is our proposed prototype.

CONCLUSION
In this paper, we introduced our initial study of an intelligent sketch-based user interface on touch- and pen-enabled computing devices, guided by child development research on self-regulation and fine motor control. Because our approach is informed by developmental and learning sciences research, our interface improves upon existing children applications that emphasize mostly on commercial appeal or entertainment value. We implemented our application EasySketch that teaches children how to draw digits/letters and can identify their fine motor skill level and the correctness of their shape drawings via our fine motor skill classifier (KimCHI) and shape recognizer (Valentine recognizer). Because our interface provides children immediate feedback on the accuracy
of their writings and drawings, children can monitor, evaluate, and make progress both in their fine motor control and their academic readiness skills.

ACKNOWLEDGEMENT

Thanks to God and St. Mary.

REFERENCES


