

EasySketch²: A novel sketch-based interface for improving children's fine motor skills and school readiness

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Abstract

Children's fine motor skills are associated with enhanced drawing skills, as well as improved creativity, self-regulation skills, and school readiness. Assessing these skills enables parents and teachers to target areas of improvement for their children, so that they are better prepared for learning and achieving once they enter school. Conventional approaches rely on psychology-based tracing and drawing tasks using pencil-and-paper and performance metrics such as timing and accuracies. However, such approaches involve human experts to manually score children's drawings and evaluate their fine motor skills, which is both time consuming and prone to human error or bias. This paper introduces our novel sketch-based educational interface, which can classify children's fine motor skills more accurately than conventional methods by automatically classifying fine motor skills through sketch recognition techniques. The interface (1) employs a fine motor skill classifier, which decides children's fine motor skills based on their drawing skills and (2) includes a pedagogical system that assists children to draw basic shapes such as alphabet letters or numbers based on developmental level and learning progress, and provides teachers and parents with information on the maturity of the children's fine motor skills that correspond to their school readiness. We evaluated both our interface and "star drawing test" with 70 children (3-8 years), and found that our interface determined children's fine motor skills more accurately than the conventional approach. In addition to the fine motor skill assessment, our interface served as an educational tool that benefited children in teaching them how to draw, practice, and improve their drawing skills.

Categories and Subject Descriptors (according to ACM CCS): Computers and Education [K.3.1]: Computer-assisted instruction—User Interfaces [H.5.2]: Evaluation/methodology—

1. Introduction

Fine motor control is a highly crucial skill for children to master for multiple reasons. Not only does strong proficiency in fine motor control allow children to similarly perform well in directly-associated physical skills such as writing and drawing [LJST11], but it is also highly correlated with positive mental traits such as creativity, self-regulation skills, and school readiness [BWCS14, LM07, Lie12]. That is, children can advance particular important physical skills and mental traits by improving their fine motor skills.

However, parents and caretakers may lack the expertise to proficiently assess quality fine motor skills, while teachers may not always be accessible in providing individualized attention in training children on those skills. Consequently, there currently

exists two strongly viable directions for attending to the assessment needs of children's fine motor skills. One direction stems from the children developmental and educational psychology research field; experts would directly analyze and make judgments on children's mental capabilities from their physical drawings (e.g., [Dia13, KMC97, LJST11]). From the other direction through the intelligent user interaction research field, sketch-based intelligent tutoring systems would automatically assess the correctness of students' input to prompted classwork problems (e.g., [VTK*12]). However, the former relies on the availability of experts, is a time-consuming manual assessment task, and can be prone to error and bias; the latter has largely focused on systems for measuring the correctness instead of the skill level of mostly adult-provided handwriting and drawing input. As a result, there is great potential in the development of a sketch-based interface for intelligent tutoring systems to advance children's fine motor skills through writing and drawing interactions and also automated guidance and assessment, in order to supplement the existing capabilities of parents, teachers, and caretakers.

In this paper, we present our proposed interface solution to alleviate the challenges of conventional fine motor skill

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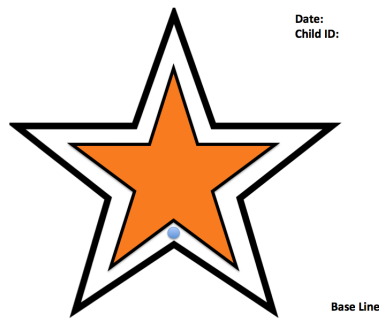


Figure 1: An example of a traditional assessment for fine motor skills (i.e. “star drawing test”). This prompts the child to draw a star within the space the two dark lines.

assessments in manual measurement and error and bias from human experts. The major contributions of our interface include the following:

1. We implemented our fine motor skill feedback system to provide richer information of fine motor skills in three different areas (i.e., overall drawing, curved shapes, and linear shapes), and adults can use this information to assist children in determining areas that they perform well and that require improvement.
2. We implemented a developmentally-appropriate interface that is capable of individualized instructions and feedback, based on children's performance and progress while they learn to draw basic shapes such as alphabet letters and numbers. From our evaluation, we discovered that children improved their drawing skills through our interface's pedagogical feedback.
3. We evaluated both our interface and the conventional methodology (i.e., “star drawing test”) (Figure 1) with 70 children between the ages of 3 and 8 years. We found that our interface can determine children's fine motor skills more accurately than the conventional methodology by f-measures of 0.907 and 0.744, accordingly.
4. During our user study, we noticed that children ages from 5 years show notable fine motor skill development than younger children (i.e. 3 and 4 years) both on fine motor skill results from our interface and “star drawing test”.

2. Background and motivation

Much of the research literature in child-computer interaction (CCI) supports the notion that when using computing interfaces, child users are not “just short adults” (e.g., [Dru02, KTV*13]), but are in fact an entirely different user population with their own culture [Ber77]. As a result when designing a sketch-based educational interface targeted to children, it is important to take into account the cognitive and fine motor abilities that are unique to them. Therefore, we first overview the relevant background literature from child developmental and educational psychology that influenced and motivated our work.

Children's cognitive and physical factors are already widely studied in the fields of developmental and educational psychology,

as both factors contribute significantly to children's school readiness [Dia13, KMC97, LJST11]. Piaget's Stages of Cognitive Development [Pia83] helps illustrate this significance by explaining how children's understanding progresses from infancy to adolescence through four different stages of cognitive development: the sensory motor (from birth to 2 years), preoperational (2-7 years), concrete operational (7-11 years), and formal operational (from adolescence to adulthood). From their cognitive development, children's generalized sensory and motor experiences contribute to their intellectual functioning [Hen10], while specialized sensory and motor experiences – through acts of sketching, drawing, and writing – provide concrete experiences and engagements to construct and represent children's knowledge and mental states [Mik14].

One important component related to cognitive and physical factors is self-regulation skills, which form the set of constructive attention and behavioral skills that affect learning. Insights from the child development research community support the importance of children developing self-regulation skills to improve not only their school readiness [Lie12], but also their completion of tasks and goals even in the face of distractions and competing interests [Dia13]. Such skills are also invaluable to children as they transition to new environments, peers, and teachers starting from kindergarten, since the skills can support their sense of mastery and confidence found in self-efficacy that lead to improved engagement in classroom activities and school work [LJST11].

Educational psychologists explore the importance of these cognitive and physical factors for assessing children's self-regulation skills such as through their gross and fine motor control. [Den07] introduces a gross motor skill assessment called “Walk-a-Line Slowly” that asks a child to walk along a line taped on the floor at regular speed and twice slowly, and assesses the child's gross motor and self-regulation skills from the averaged score of two slow trials. [VIR12] determines fine motor skills through sketch correctness from a child copying a circle, and assesses their performance from their production of predominantly circular lines. [KMC97] incorporates a battery of fine motor control assessments for effortful control and behavioral self-regulation skills that includes requiring a child to trace with a pencil basic geometric figures at different speeds – normal, slow, or fast – without deviating from their figure outlines (Figure 1), and measures the drawing time difference between the slow- and normal-speed drawings [Den07, LJST11] and error rates (i.e., the number of points that going outside the lines of the figure) from fast-speed drawing [LJST11]. However, the weaknesses of these assessments from researchers include (1) the necessity of their time-consuming manual efforts, (2) the proneness to error due to individual bias from their own manual measurements (e.g., each researcher's contrasting opinions for deciding whether a child's drawn circle is predominantly circular lines), and (3) the narrowness of features for correlating between a child's fine motor skills and error rates.

From the self-regulation skills of gross and fine motor control, the latter plays more of a crucial role in children's mastery of basic classroom skills (e.g., writing and drawing) [LCH10]. For example, many children draw shapes in kindergarten classes with

writing implements such as crayons and pencils that demand a certain level of proficiency in fine motor skills [LJST11]. Many developmental and learning scientists have found evidence that fine motor control can predict children's social, communication, and study skills [LJST11]. Children benefit from nurturing their creativity through drawing and from developing metacognitive and memory strategies through handwriting [BWCS14, LM07], which are developed through integrated sensory modalities such as vision, motor commands, and kinesthetic feedback [Mik14]. As a result, improved fine motor skills through drawing practice correspond with children's improved creativity and self-regulation skills that are highly important in the success of their school readiness and future achievement.

3. Related work

As touch- and sketch-based interactions become more commonplace, interactive technologies such as surface computing or natural gesture interfaces will enable new means of motivating and engaging students in active learning in next-generation classroom and educational environments [ABT*13, DPH10, TH09, TBH15].

However, there are major challenges in developing applications specifically catered for children, including appealing to children's interests due to their tendency to lose focus more easily than adults, and making an application more age-appropriate so that children are not frustrated by the difficulty of the application or its simplicity [KTV*13]. To meet these requirements, designs need to have strong consideration in developing both engaging features and compelling contents. One of the example works is *TAYouKi* [VTK*12], which includes an agent system that emulates emotions based on the correctness of their drawings. The cartoon-style face changes the emotion by the user's sketch correctness history with supplementary text and sound feedback. However, one of the major limitations of this application is that it only recognizes shape correctness not fine motor skills. Second, the application is using adult-trained sketch recognizers, and it performs worse for children. Furthermore, the application does not guide children to make correct shape drawings, but only determine the correctness of their drawings.

There are many sketch-apps on touch-based devices run on iOS or Android. The apps provide learning materials to help preschoolers to develop their fine motor skills through drawing. These applications can help the preschoolers' readiness for kindergarten. One of the examples is "Dextra Jr." by BinaryLabs [Bin13]. From the application children can practice fine motor skills by drawing. "PBS Parents Play & Learn" [PBS] provides many useful learning materials that includes simple mathematical examples and drawing examples. Children can follow instructions to draw alphabets. The application also supports drawing directions to teach children draw shapes with correct orders. As a result, these applications provide activities that encourage children to enhance their fine motor skills by drawing. The applications also include many interesting animations to encourage children to enjoy drawing. We can hope that these practices actually enhance children's fine motor skills. Unfortunately, these applications do not recognize children's fine motor skill levels automatically, but only have simple fine motor

skill activities, which cannot describe whether preschoolers' fine motor skills reached more matured level like those of grade-schoolers.

Kim et al. [KTV*13] implemented a sketch-based interface and a fine motor skill classifier that is able to assess children's fine motor skill development. The application asks children to draw basic shapes such as alphabet letters or digits. Whenever a child draws a shape, the application determines the child's fine motor skill level and provides feedback as "mature" or "in training". When the child finishes their drawing activities, they will receive feedback on how many times they drew the shapes correctly. However, the limitations of this study are that (1) the study solely evaluated their classifier, which is missing evaluation performance study over to the traditional assessments [Den07, LJST11]. As a result, there is no clue that their interface can alleviate the limitations of the traditional assessments; (2) the feedback only provides fine motor skill stages per sketch. Because the interface cannot sufficiently capture children's ongoing developmental stages, it cannot assist their parents to determine areas that they perform well and require improvement; (3) children may become discouraged if they get feedback that their fine motor skill is "in training" whenever they draw; (4) the application does not have a pedagogical feedback system that assesses children's learning progress and provides assistance to draw shapes; and (5) their user group has many age gaps. Their study group included age 3-4 years and 7-8 years. According to educational psychologists, age 2-7 are rapidly developing their fine motor skills with various developmental stages including fine motor skills [Pia83]. To better assess their fine motor skill development per age, our study includes continuous age 3-8 years' sketch data.

4. Field study

Prior to designing our interface, we engaged in an ethnographic study in a preschool classroom environment. Because ages 3-4 years are active ages in which children learn basic shapes, we specifically targeted this age group for our study. The classroom we observed included ten preschoolers and two teachers. We observed the preschool class over the course of five consecutive school days for thirty minutes per day. Prior to our study, we spent some time becoming acquainted with the children and teachers in the preschool classroom, in order for the children to be better acclimated to our presence and for the teachers to become more aware with our study approach.

From our five-day visit, we observed one teacher spending time each day teaching the alphabet to their preschoolers. We learned from the teacher that a different letter to discuss in the class changes weekly, and that the letter that was taught as we observed was the letter 'S'. During this class time, the preschoolers were seated on the ground as the teacher taught, standing in front of them for approximately ten minutes per day to teaching concepts regarding that letter. The instructional process that the teacher followed during our visit is elaborated as follows: (1) the teacher shows a letter on paper and demonstrates sounding the letter out to the preschoolers. The teacher also introduces English words starting with the letter 'S' (e.g., "snake"), and the preschoolers imitate pronouncing the words; (2) the teacher demonstrates how

to physically draw the letter on paper to the preschoolers; (3) the teacher draws the letter on each child's back and arm using their finger. The teacher also holds each preschooler's fingers grasping a pen, and the two draw the letter together; (4) each child plays with a piece of paper that contains the letter; and (5) each child places a sticker containing the letter on a diagram of a letter tree.

From this instructional lesson, the preschoolers were able to learn the letter shapes using a variety of integrated sensory modalities such as vision, motor commands, and kinesthetic feedback. We also found that there were many books and posters that teach children how to draw alphabet letters with gestures using tracing dots and arrows. During an interview with the teachers, they explained that children can develop drawing skills by drawing practice, and also shared that tracing dots with drawing gestures help children to more easily follow the letters' drawing gestures and learn the letters. They also explained that there is no correct drawing gesture, but there are common drawing gestures on digits and letters, which can also help children's school-readiness. They periodically assessed children's fine motor skills every six months by asking children to draw basic shapes (e.g. 'circle') and counted the correctness manually. However, they issued the difficulty of the test that we explained in the prior section (i.e. prone to error from bias and need manual effort).

From the ethnography study, we found that (1) children like drawing; (2) tracing dots with drawing gesture can assist the children to develop their fine motor skills and school readiness; and (3) automatically assessing their sketch correctness and fine motor skills would be helpful to reduce human efforts. In order to assist children to develop their fine motor skills, we chose our application enables sketch-recognition technique and employ tracing dots with drawing gestures in the interface to assist how to draw basic shapes.

5. Methodology

5.1. Drawing assessment system

Before describing our interface, we first provide information of our drawing assessment system. The system combines the capabilities of three relevant sketch recognition algorithms to assist in providing human expert-emulated assessment on children's sketches of basic shapes. Specifically, the recognizers that we incorporated specialize in providing feedback on children's (1) *fine motor skills*, (2) *shape correctness*, and (3) *gesture correctness*. Figure 2 explains the architecture of our drawing assessment system.

5.1.1. Fine motor skill classifier

In order to handle classification of children's fine motor skills, we employed KimCHI [KTV*13], a gesture-based classifier. As we mentioned earlier, the major drawback of the current methodology (i.e. "star drawing test") is that the methodology does not analyze children's sketches. The KimCHI [KTV*13] classifier resolves the drawback of the current methodology by focusing on recognizing the physical act of how sketches are made (e.g. smoothness of curvature-drawing). The classifier first calculates a dimensionality-reduced subset of gesture-based sketching features (e.g., angle between important sketch points, total change in angle), derived

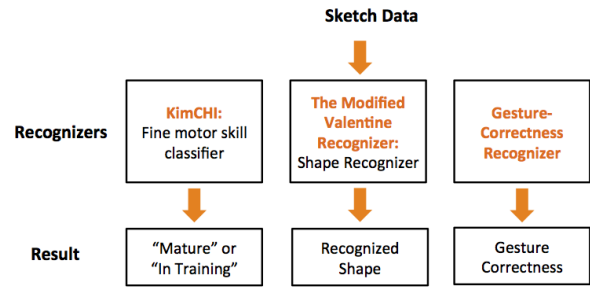


Figure 2: The architecture of our drawing assessment system consists of the following components (L-R): the fine motor skill classifier, the shape recognizer, and the gesture-correctness recognizer.

from 130 features in the existing sketch recognition techniques of [FPJ02,LLRM00,PRD*08,Rub91]. After that, Random Forest + Bagging machine learning technology determines the sketch's label (e.g. mature or non-mature) based on the sketch features.

The KimCHI classifier could determine the fine motor skills of sketches as either non-mature (i.e., the level of preschoolers) or mature (i.e., the level of grade schoolers and adults), with an f-measure of .904 using 10-fold cross-validation. The selected features during classification process were mostly curvature- and line-related features such as "direction change ratio" and "slope of the direction graph" [KTV*13, PRD*08]. Therefore, KimCHI [KTV*13] predicts children's fine motor skills automatically by measuring whether they can draw curvatures and lines smoothly using curvature- and line-related features, which can assess their drawing skills.

Since KimCHI performed well in classifying the performance of children's fine motor skills, we chose to take advantage of the classifier in our interface's drawing assessment system for determining children's fine motor skill levels.

5.1.2. Shape correctness recognizer

We assess the correctness of children's sketched shapes using the child-trained recognizer [Kim12], which is a modified version of the Valentine recognizer [VVL*12]. The recognizer takes as input two shapes: one template shape, whose shape definition is known; and one user-generated shape, whose shape definition is unknown. The recognizer will output a value between 0 and 1 that reflects the confidence that the two shapes are similar, where 0 denotes no confidence and 1 denotes complete confidence. To calculate this confidence, the recognizer first scales and translates the shapes into a 48×48 bounding window to ensure both shapes are approximately the same size. Subsequently, the recognizer resamples the points in both shapes so each is made up of 48 equidistant points [Kim12].

After preprocessing, the recognizer considers each point in each shape – 48 equidistant points from both shapes for a total of 96 points – and then records the distance from that point to the closest point in the other shape. From these shortest distances, it calculates

similarity values from the Tanimoto coefficient [KS04, VVL*12], which is the ratio of points with shortest distances less than 4 pixels over the total number of points. If that confidence value is above its empirically defined threshold of 0.65, the two shapes are deemed similar [FVLH11, KS04, Kim12, VVL*12]. As a result, the user's shape could be defined by the template's shape definition. The recognizer labels the user shape with the shape definition of the template with the highest similarity confidence value.

The merit of this recognizer is its extensibility. Whenever we want to add shapes to be recognized, we only need to add one sample shape as a template. Our application takes advantage of the modified Valentine recognizer to inform users whether they have drawn the prompted shape correctly.

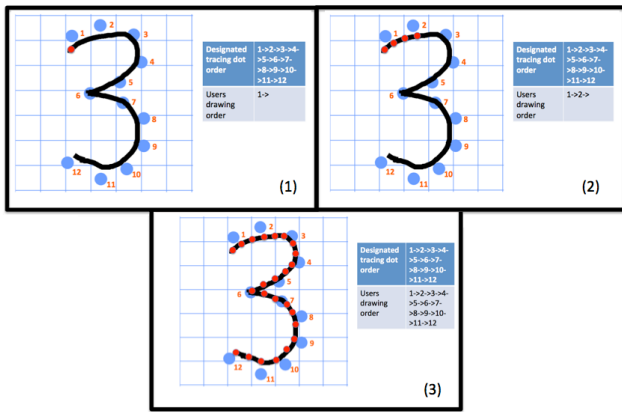


Figure 3: The recognizer calculates the distance between the tracing dots and the user's shape. (1) It first calculates the distance between the first desired tracing dot (number "1" in Figure) and the user's point. If the point is within distance threshold with the tracing dot, we add it to the user's drawing order list, (2) Next, it calculates the distance between the next desired tracing dot (number "2" in Figure) and the user's point. If the point is within distance threshold with the tracing dot, we add it to the user's drawing order list, and (3) Finally, it compares the user's drawing order list with designated tracing dot order list. In this example, the drawing gesture was drawn correctly.

5.1.3. Gesture correctness recognizer

Lastly, we developed a specialized naive recognizer for handling the correctness of gestures from the set of letter and number shapes in children's sketches. For example, the recognizer can determine whether a child drew the number '3' by starting at the top and curving downward, or whether the child instead started at the bottom and curved upward. In order to do so, we first produced tracing dots, which have certain order of drawing. The recognizer calculates the distance between the tracing dots and the corresponding user's shapes, and adds a tracing dot to an ordered list if the points in the user's sketched shape lie within a certain distance threshold of that tracing dot. If the complete list of tracing dots is added and in the desired order, our recognizer then determines the user's shape as correct (Figure 3).

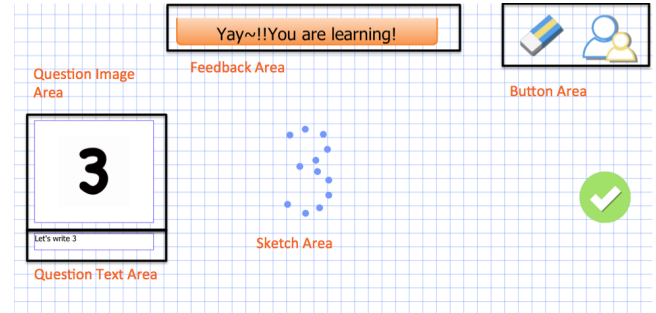


Figure 4: The application's pen user interface. The interface will show the tracing dots on the drawing area when the child is not able to draw the shape correctly.

5.2. User interface

We target our interface for preschoolers, whom conventionally fall within the age group of 3-6 years in the United States, are still developing their fine motor skills, and are preparing for kindergarten. Our target user group additionally includes children whom are enrolled in kindergarten but are lacking in age-appropriate fine motor skills compared to their peers.

Designing an interface for children has its own unique set of challenges. Interfaces for such applications should capture and maintain the interests of children that they hope to cater to, since children can easily lose their focus using applications that do not gauge their interest. In order to address the challenges of maintaining children's attention, we primarily considered the following:

- **Ease of use.** Since preschoolers are one of the core target users of our application, a child should ideally be capable of independently using the sketch user interface, following an initial guided practice with a parent or teacher.
- **Ease of following.** The application should include animations and tracing dots for showing a child how to draw basic shapes and easily explore the problem space.
- **Positive and straightforward feedback.** The target users should be presented with the results of our three recognizers in a developmentally-appropriate and exciting way. Since informative and immediate feedback are crucial to children's motivation, our interface includes text feedback and audio cues that specifically cater to children. Furthermore, children can get frustrated easily from their negative outcomes. Because positive social comparative feedback was found to enhance learning of children [ACWL12], we made our feedback positive even in the face of negative outcome. For example, if a child's sketched input is incorrect, then the application reveals the text feedback of "Yay! You are learning" while simultaneously playing an audio cue corresponding to that result (Feedback Area in Figure 4).

Figure 4 depicts the user interface of our application containing the following five areas:

- **Question Text Area.** Prompts the child to sketch the shape.

- **Question Image Area.** Displays an animated image of the prompted shape, as well as instructions on how to draw that shape.
- **Feedback Area.** Displays the text feedback.
- **Sketch Area.** The space for children to sketch the shapes.
- **Button Area.** The collection of interactive buttons consisting of buttons for erasing and reporting. The report button is used to prompt the application to check the fine motor skill level from the sketch.

5.2.1. Procedure

Figure 5 explains the overall procedure of our interface. The application will let a child attempt to draw the shape correctly three times at maximum before moving on to the next question, and we designed the application as such so that the child does not feel frustrated or lose interest due to a single question. Our interface displays an animated image (*Question Image Area* in Figure 4) that shows the correct drawing gesture in the instructions area for the child to learn or reference. When choosing "correct" drawing gestures, we referenced books recommended by our field-study preschool teachers (e.g. [Ste13]).

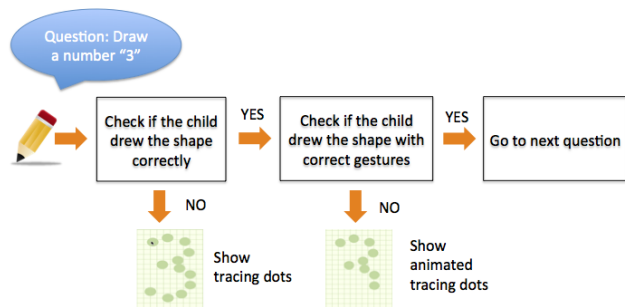


Figure 5: The application displays different instructions that are dependent on the child's drawing correctness and learning progress.

5.2.2. Pedagogical feedback system

As preschoolers develop their cognitive and fine motor skills, they apply these skills as they are learning at their own individual pace and approach [Pia83]. We observed this learning contrast from the children in our user study, where many of the younger children (i.e., 3-4 years) lack knowledge of how to draw basic shapes compared to their older counterparts (i.e., 5-8 years). Due to these contrasts in domain knowledge, we developed the pedagogical feedback system of our application to support children's individual learning differences (Figure 5). Naka discussed that repeated hand writing facilitates children's learning [Nak98]. To help children's learning, our pedagogical feedback system evaluates children's drawing, and asks children to repeat drawing when they could not draw the shapes correctly. Specifically, our system first determines the shape and gesture correctness of each child's sketched input, and then provides differential instruction based on that determination. If the child sketched and gestured the shape correctly, the child will proceed to the next question with a new prompted shape (e.g., the

number '4') with corresponding sound and text feedback. However, if the shape was incorrect, the application displays tracing dots of the corresponding shape for the children to guide their drawing to the correct sketching motions on *Sketch Area* (Figure 4). If instead the user drew the shape correctly but with an incorrect gesture, the child will be shown animated tracing dots on *Sketch Area* (Figure 4). A tracing dot will appear every second in order to demonstrate to the child what the correct sketching motion is.

Once the child finishes the lesson containing the set of shapes as defined by the teacher or parent, the application automatically assesses the child's fine motor skill level. The post-lesson report screen (Figure 6) revealed after the child completes the lesson allows for the parent or teacher to receive an assessment of the child's fine motor skills per overall, curved (e.g. number '3'), and linear (e.g. number '1') shapes as "in training" or "mature", which provides a richer feedback rather than current manual assessments [Den07, LJST11] that only determine overall fine motor skills and automatic assessment [KTV*13] that only determines fine motor skills per drawing. Our report's information can better assist these adults in determining areas of improvement on the child's sketching performance, such as whether the child is struggling with curved or linear shapes, or whether the child is conceptually understanding or skillfully drawing the shapes.

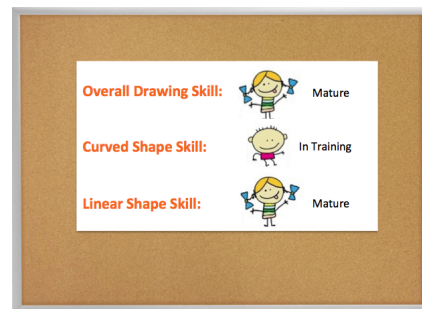


Figure 6: A feedback window for parents and teachers to view our system's assessment of their child's fine motor skills performance.

6. Results

Research questions were tested to understand children's development of drawing and fine motor skills and our interface in assessing and teaching those skills. Specifically, we tested three research questions.

1. Question 1 (Age Development): At what age do children show notable fine motor skill development?
2. Question 2 (Approach Comparison): Does our interface classify children's fine motor skills more accurately than the conventional method ("star drawing test"), and why does our method work better?
3. Question 3 (Child Improvement): Do children improve their drawing skills through our interface?

6.1. Participants

We conducted a user study with a total of 89 children from, which we collected 1,853 sketches. The demographic characteristics of

our participants are displayed in Table 1. Our hypothesis was that older children (i.e., 5 years or more) would demonstrate better fine motor skills than younger children (i.e., 3-4 years), so we segmented the users into those age groups to represent younger and older children.

Table 1: Demographics of the child participants' user groups

Age Group	Group size	Male/female	# of sketches
3-4 years old	54	24/30	1,082
5-8 years old	35	14/21	771
Total	89	38/51	1,853

6.2. Study procedure

89 children completed the assessments from our interface (Figure 4) and 70 children (39: ages 3-4 years and 31: ages 5-8 years) volunteered to complete the additional conventional assessments (i.e., "star drawing test") (Figure 1). All children were told that participation was voluntary and that they could stop participation at any time if they want. However, every child chose to complete the session, which typically lasted approximately 20 minutes. All children were accompanied by their parents for this study.

To conduct the user study, we traveled either to the child's home or school, or performed the user study at our research lab. In the case that the study took place at school, we conducted the study in a private room without distractions to participants. Before we began each user study, we gave a brief explanation of the purpose of our study and the importance of evaluating fine motor skills.

The user study included one or two sessions. Every child (a total of 89) performed our interface test study, and 70 children volunteered to take the "star drawing test" as well. For the "star drawing test", we first conducted the test [LJST11] using the conventional pencil and paper method (Figure 1) at three different speeds – where the child was initially asked to draw (with no instructions on the speed in order to assess their natural or normal drawing speed), then instructed to draw fast, and then to draw slow – and measured their drawing durations manually using a stopwatch. Afterwards, we provided a Surface Pro 2 and a digital stylus to the child. With our application running on the tablet, we asked the child to draw shapes using the stylus in the presence of the parent by their side. In order to ensure that we procured the children's natural drawings and a clear understanding of the usefulness of our instruction system, we requested the parent to not help their children's drawings. The interface test session had two parts: (1) *free drawing without our pedagogical feedback system*: the child first drew basic shapes (i.e., line, two lines, rectangle, square, curve, and triangle) each twice, which are generally used for assessing their domain knowledge and fine motor skills at preschool; and (2) *instructed drawing with our pedagogical feedback system* (Figure 5): they drew digits (1-3) and capital alphabet letters ('A', 'B', and 'C'), which we chose for the representative study data. Our interface assessed their fine motor skill results from each drawing using the KimCHI classifier [KTV*13] – including the basic shapes – and finally saved an overview of the results to a spreadsheet.

6.3. Answering question 1: age development

In order to assess children's fine motor skill development by age, we introduce the result of (1) "star drawing test" and (2) our interface test.

6.3.1. Star drawing test

The "star drawing test" uses only drawing time differences for assessing fine motor skills. However, we collected both drawing time differences and error rates (i.e., the number of points that going outside the lines of the figure) for assessing children's fine motor skills that was introduced in [LJST11], in order to determine if there were age differences in children's drawing times or error rates. We manually measured the error rates from the fast-speed drawing and calculated the drawing time difference between slow- and normal-speed drawings. Recall that we classified children aged 3-4 years as younger and children aged 5-8 years as older. We hypothesized that older children will have greater fine motor skills, as indexed by greater time differences and smaller error rates, in their drawings than younger children.

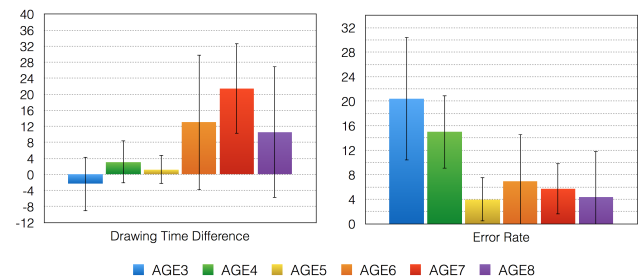


Figure 7: We found that after six years of age, the drawing time difference increased significantly. From five years of age, error rates significantly decreased. However, the standard deviations of each age group were large for the drawing time differences and error rates.

Figure 7 displays the average values of time differences and error rates. As seen in Figure 7, the drawing time difference significantly increases from age 6 years and error rate significantly decreases from age 5 years (which explains better self-regulation and fine motor skills [Den07]). We believe one explanation for this finding is that ages 5 and 6 years are the ages in which children enter kindergarten in the United States, and thus will have more practice drawing at school than younger children (3-4 years). Furthermore, kindergartners (5-6 years) are typically more advanced in their physical and motor development than preschoolers (3-4 years). During the user study, the parents of age 5 and 6 years explained that they frequently practice drawing for school-readiness. We believe that increased practice and advanced physical development partly explain the sharp improvements observed in age 5 and 6 years' fine motor skills.

6.3.2. Interface test

To assess the fine motor skill development by age, we calculated similarity values of children's digital drawings from interface test

using the modified Valentine recognizer [Kim12, VVL*12]. As we explained earlier, the recognizer returns a similarity value which lies in the [0..1] interval, with 1 denoting that the user's drawing is identical to the designated shape. As a result, if the similarity value of the child's drawing is closer to 1, it means the child drew a shape correctly. Figure 8 explains our similarity value results of the children's digital drawings from our interface test (Left of Figure 8: overall similarity value for each age group, Right of Figure 8: detailed shape (i.e. digits: 1, 2, 3, and letters: 'A', 'B', 'C') similarity values for each age group). When we assessed the children's similarity value by age, the pattern of results suggest that after approximately 5 years, their similarity values were higher than younger children. Furthermore, when we assessed each age group's standard deviations of similarity values from the overall shape drawings (Left of Figure 8), young children had higher standard deviations in their similarity values (0.188: age 3 and 0.203: age 4) than older children (lower than 0.15). As a result, we believe that the similarity value results will indicate their fine motor skills, and after ages 5 and 6 years children will have better fine motor skills than younger children, which corroborates our results from the "star drawing test".

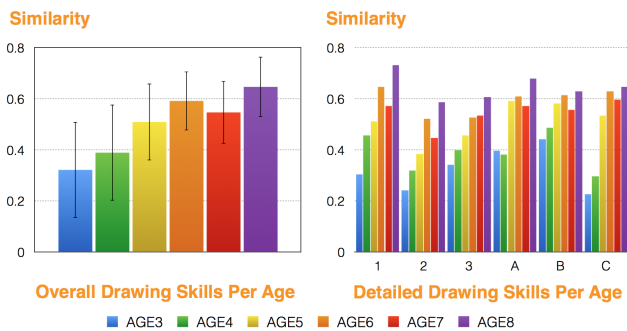


Figure 8: The results of the similarity values for each age group (left: overall similarity values per age ; right: detailed shape similarity values per age). When we assess the children's similarity value by age, after about five years age, their similarity values were higher than younger children.

6.4. Answering question 2: approach comparison

As previously mentioned, a major problem with conventional assessment approaches (i.e., "star drawing test") is that it does not assess children's drawing skills, but instead only measures their drawing time differences and accuracies. Since our interface's fine motor skill classifier assesses drawing skills by "how they drew", we hypothesized that our interface would perform better than the "star drawing test". To compare the fine motor skill classification performance between our interface and the "star drawing test", we followed the following procedures:

1. To assess children's actual fine motor skill levels, we employed a style of measurement [Chi11], which was used at the preschool during our initial field study. This measure indicates that as children develop, they are better able to draw greater number of shapes. During the field study, the teachers asked

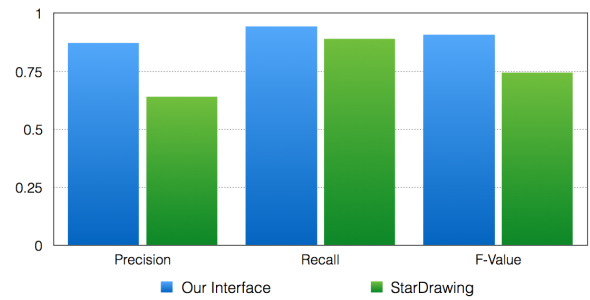


Figure 9: Comparison metrics between our interface and "star drawing test". Our interface determined children's fine motor skills more accurately than the "star drawing test"

children to draw basic shapes such as square, and labeled their fine motor skills maturity. In our study, three experts (i.e., a computer scientist and two elementary school teachers who both have experience with young children's sketches) met and manually labeled the fine motor skills for each child. The experts viewed printouts of the basic shape sketches (i.e., line, two lines, circle, rectangle, square, and triangle) that were drawn on the tablet during the interface test, and the experts determined their drawing correctness and labeled their fine motor skill levels as "mature" if the children drew the every basic shape correctly, and labeled "in training" otherwise.

2. To assess children's fine motor skills from the "star drawing test", we first decided the age 6 years' mean time of time difference for our threshold, because we found that after age 6 years, they have sudden changes in drawing time difference in our study (Figure 7). We chose 11.5 seconds to be the threshold, which was the mean time of age 6 years from the study [Den07] as they included more child participants than us. If a child's drawing time difference is higher than 11.5 seconds, we then labeled their fine motor skills as "mature".
3. We assessed children's fine motor skills from our interface test that the KimCHI classifier [KTV*13] determined their skills as either "in training" or "mature".

Figure 9 shows the results of our system compared with traditional assessments. Our interface classified children's fine motor skills with a precision of 0.872, a recall of 0.944, and an f-measure of 0.907. On the other hand, the "star drawing test" classified their fine motor skills with a precision of 0.64, a recall of 0.899, and an f-measure of 0.744. This verifies that our interface classifies fine motor skills better than the traditional "star drawing test" assessment.

6.5. Answering question 3: child improvement

In order to assess whether or not children improved their drawing skills with our interface, we compared similarity values from the modified Valentine recognizer [Kim12, VVL*12] of the sketches before (i.e., their original drawing) and after following tracing dots. As we described earlier, if the similarity value of the child's drawing is closer to 1, it means the child drew a shape correctly.

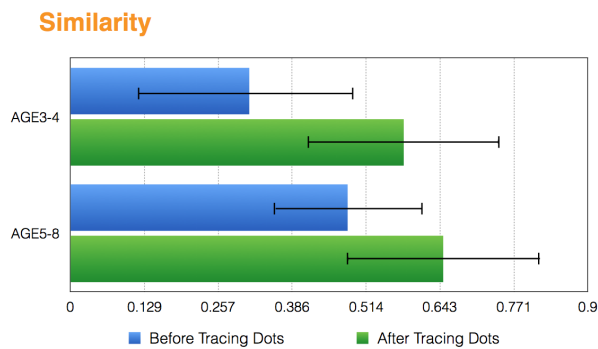


Figure 10: After following the tracing dots, the young children's similarity value were improved by 0.268 and the older children's similarity value were improved by 0.166.

As a result, if the similarity value increases after following tracing dots, it means they can draw shapes better than before tracing dots (better drawing skills).

When we grouped the children as young children (age 3-4 years) and older children (age 5+ years), each group improved their drawing skills with higher similarity values after following the tracing dots (Figure 10). We also noticed that young children remarkably improved their drawing skills by 0.268. Their parents positively evaluated our interface that improves their children's drawing skills. Examples of the feedback from their parents included:

- **Parent of child 1 (age 3 years):** At first time, she could not draw the alphabet 'A' correctly. And, I didn't believe that she would follow tracing dots well. However, when the interface showed the tracing dots, my kid followed the tracing dots and finally drew the 'A'!
- **Parent of child 9 (age 3 years):** It is hard to teach how to draw shapes on paper to my kid because she does not enjoy drawing. However, she enjoyed this software because it runs on computer. The tracing dots were easy to follow.

7. Discussion

From our user study results, we found that children drew the desired shapes more aligned to the model solutions (enhanced drawing skills) from using our pedagogical feedback system and tracing dots. We also observed that our interface classified children's fine motor skills more accurately than the traditional "star drawing test" assessment, and believe that this result stems from limitations of the conventional assessment method.

The first limitation was from high variation of drawing time differences and error rates across age groups. As seen in Figure 7, the standard deviations of drawing time differences of each age group was high, especially in the ages of 6-8 years. Figure 8 also shows high variations of similarity values of children's drawings in age group. Given the high standard deviations, the time differences did not differ across ages, except possibly in the case of 5 years.

Thus, time differences and error rates were not reliable features for fine motor skill evaluation.

The second limitation was that the "star drawing test" only measures drawing time differences and accuracies. During our user study, one 3 year old child earned a "mature" rating from the "star drawing test" because the value of the child's drawing time difference between slow (28.32 seconds) and normal drawing (15.98 seconds) was 12.34 seconds, which is higher than our drawing time difference threshold (11.5 seconds), which was the mean time of age 6 years from the study [Den07]. However, when we assessed the child's drawings, the child could not draw many of the basic shapes such as circle or square, and our interface reported that the child's skills were "in training" not "mature". Another example is a 6-year-old child who drew every basic shape (e.g. circle and square) correctly. The child was very careful about drawing when no speed instructions were given (i.e., normal drawing time of 20.95), so when the child was instructed to draw slowly, he drew only 4.52 seconds slower. The "star drawing test" labeled this child as "in training" because the initial conscientiousness meant that the time difference did not meet the 11.5 seconds threshold for "mature". However, our interface determined that same child's fine motor skills as "mature".

8. Future work

During our user study, we found that our interface classified children's fine motor skills better than the conventional approach and improved children's drawing skills. To further validate the usability of our interface, we are planning to employ our interface to preschool or clinic and conducting a longitudinal study. From the study, we will further test our interface and its impact on improving young children's fine motor skills and school readiness.

9. Conclusion

In this paper, we describe EasySketch², a novel sketch-based interface for improving fine motor skills and school readiness. In order to assess children's fine motor skills more correctly and reduce experts' manual efforts, we designed, developed, and evaluated our interface to automatically assess and provide more detailed analysis. The interface determines children's fine motor skills, teaches them how to draw, and provides their fine motor skills and school readiness information to parents and teachers. From our evaluations, our interface performed better in assessing children's fine motor skills compared to the conventional approach (i.e. star drawing test), while children improved their drawing skills through feedback from our pedagogical system. Furthermore, we discovered from our user study that there is a prime period of growth at five years of age, who have markedly better fine motor skills than younger children (i.e. 3-4 years). We believe that their increased opportunities for practice and growing physical and motor development played a strong role in sharp improvements of their fine motor skill stages. As children become more exposed to using pen and touch interactions [RMC02], we also believe that this research can assist researchers, designers, and educators in assessing children's fine motor skill stages on digital drawings, while also supporting children's self-regulation skills and school-readiness.

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