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Research Article

A mathematical model for suitability of smartphone apps for children

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Children now get access to smartphones at an early age and gradually acquire skills to use different types of smartphone apps. We developed a mathematical model for the ability and interest of children to use smartphone apps. The model can be used to determine the level of difficulty of apps and identify niche app, *i.e.* apps that are designed specifically to be used by a narrow age range of children. We used the model to analyze nine apps that are used by children. We found three of the apps to be of suitable difficulty level, four of them to be too easy and two of them to be too difficult for children who are interested in using them. We were also able to identify three niche apps.

1. Introduction

A smartphone is a mobile phone that has computational power comparable to that of a personal computer. A smartphone has an internal organization and an operating system similar to those of a computer. The operating system of a smartphone facilitates the execution of user programs, colloquially known as apps. A smartphone has one or more cameras, a microphone, a speaker and support for multimedia. A smartphone can be used to connect to the Internet and also has sensors like an accelerometer and a GPS receiver that enhances its utility and mobility [1]. However, best recognized feature of a smartphone is its touchscreen. The touchscreen spans almost the entire front side of a smartphone and acts as both an input device and an output device.

Affordable smartphones became available in the early-2000s and the number of people using smartphones has been steadily increasing ever since [2]. Today, smartphones are used around the world by people of different ages and professions. Low Internet tariff and the availability of apps for various purposes encourage people to use smartphones. People use smartphones for communication, educational purposes, professional commitments and leisure.

Smartphones are known for their narrow gulf of execution, *i.e.* the gap between what has to be done and how it can be done. This allows non-expert casual users to use smartphones almost like tech-savvy professional users [3]. Many casual users are intimidated by the input devices of a computer like keyboard and mouse. The touchscreen of a smartphone displays icons and simple menus that a user can manipulate intuitively. Additionally, smartphone apps typically display less information at a time and use only simple widgets which further help casual users. There are people who are not comfortable in using computers but can use smartphones with ease.

Nowadays, innumerable smartphone apps are used by people to assist them in their daily activities. Smartphone apps to pay bills, forecast weather, track fitness, shop for grocery items and teach cooking are a few examples of the wide variety of apps that are used by people. Social media apps and video chat apps are highly popular in societies with diverse socio-economic background to share their day to day status and maintain close interaction with relatives living in far off places. In addition, smartphone apps for entertainment, teaching and learning are popular among leisure driven users, knowledge seekers and information providers,

respectively. Smartphone apps like game apps, roleplay based apps, storybook apps, drawing apps, encyclopaedic apps and collaborative learning apps have been found to be liked by children while growing up. Parents and teachers often download popular educational apps to teach novel words, and concepts of science and mathematics, and encourage children to augment their learning through the well conceptualised content of these smartphone apps. Even though children are exposed a lot to science and mathematics content through smartphone apps nowadays, our understanding of how much children can learn from their interaction with mobile devices and how children achieve the same is in the nascent stage.

1.1. Child-Smartphone Interaction. Yan [4] has recently remarked that how children's understanding of emerging technologies originates is an important question from the perspectives of human evolution as well as development of technology. Children are exposed to digital devices at an early age [5]. Young children typically interact more frequently with smartphones than other digital devices [6]. Parents often play music and videos on their smartphones to pacify crying children or entertain them when they are just few months old. Children are attracted to smartphones because of their small size and stylish design and the functionalities they provide. Children can hold a smartphone firmly in their hands by the age of two years [7]. Children gradually acquire various skills required to operate smartphones. They learn to acquire targets on the screen, perform various touchscreen gestures [8–10], follow instructions provided by apps [10, 11], navigate hypertext [12] and use augmented reality software [13] by eleven years of age. A skill, once acquired, is retained by children.

Children constitute the largest class of non-expert users of smartphones. Different types of apps are used by children while growing up. Children younger than two years are passive users of smartphones. They can listen to music and watch videos played on smartphones and even knowingly participate in video calls made using smartphones but do not try to operate smartphones. At around two years of age, children begin to make efforts to operate smartphones. Children aged two and three years can use drawing apps and simple games. Children aged four to six years can use vocabulary apps, quiz apps and other educational apps. Children aged seven and eight years can use encyclopaedia apps and educational games. Children aged nine years and more can use web browsers and instant messaging apps. Children are interested in using an app for a few years, however, with increase in age the app fall out of their interest and they become fascinated by more sophisticated apps. Children typically regard smartphones as tools to support their academic and co-curricular endeavors, while many parents and teachers are not supportive of the use of smartphones by children [14].

Smartphone apps meant for entertainment and learning of children can be effective only if children are inclined to use those apps and the children also possess the skills required to use those app. Children in different age groups have significant difference in their physical and cognitive abilities [15]. Studies investigating the relationship between abilities and interests of children to use smartphone apps are largely missing from the literature. Consequently, smartphone apps for children are often found to be designed without due consideration of the abilities and interests of the target age group of children.

Although child-smartphone interaction has been an active field of research for more than a decade now, no mathematical model of abilities and interests of children to use smartphone apps has been developed yet. In this paper, we develop a mathematical model of applicability and suitability of smartphone apps for children based on the results of empirical studies conducted before.

2. The Model

Researchers have been studying the interaction of children with the smartphone apps for the last two decades. We have been working on this topic for the past five years and have studied how children of different age groups interact with different types of apps. In our previous studies, we were able to identify the most important skills needed by children to use smartphone apps. We have also observed how the interest of children about various apps changes with age. In the present study, we used the results of our previous empirical studies to construct a mathematical model of child-smartphone interaction. The model is based on probability theory and studies the relationship between the proportion of children who are able to use an app and the proportion of children who are interested in using the app at different ages.

2.1. Ability of Children. We use a parabola to model how children acquire a certain skill (Figure 1). Let x_1 be the age at which some children acquire the skill and x_2 be the age by which all children acquire the skill. The values of x_1 and x_2 may be determined empirically. Since the vertex of the parabola is at $(x_1,0)$, the proportion of children who have acquired the skill at the age x is as follows.

$$y = \sqrt{4a(x - x_1)} \tag{1}$$

Since all children acquire the skill by x_2, the value of a can be calculated as follows.

$$a = \frac{1}{4(x_2 - x_1)} \tag{2}$$

2.2. Interest of Children. We use a Gaussian function with unit height to model the interest of children about an app (Figure 1). Let x_3 be the age at which 10% children are interested in using the app and x_4 be the age at which all children are interested in using the app. The proportion of children who are interested in the app at the age x is as follows.

$$y = e^{-(x-x_4)^2/2c^2} \tag{3}$$

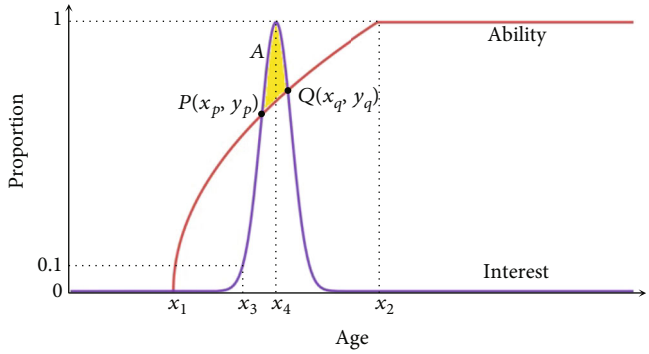

FIGURE 1: Ability and interest of children to use a smartphone app.

Since the curve passes through $(x_3, 0.1)$,

$$0.1 = e^{-(x_3 - x_4)^2/2c^2} \tag{4}$$

Now, the value of c can be calculated as follows.

$$c = \sqrt{\frac{(x_3 - x_4)^2}{2 \ln 10}} \tag{5}$$

The parameter c represents the applicability of an app, *i.e.* the size of its target audience. If $c \leq 1$ for an app, then we call it a niche app.

2.3. Relationship between Ability and Interest. We use a parabola to represent the most important skill required to use an app. Let the parabola (vide Equation (1)) and the Gaussian function (vide Equation (3)) for that app intersect at two points, *viz.* P (x_p, y_p) and Q (x_q, y_q). Since the equations of the parabola and the Gaussian function cannot be solved algebraically, computer simulation may be used to determine the values of x_p and x_q. Let A_1 be the area below the Gaussian function between x_p and x_q. Since an indefinite integral of a Gaussian function does not exist, we use an approximation as follows.

$$A_1 = \int_{x_p}^{x_q} e^{-(x - x_4)^2/2c^2} dx \int_{-\infty}^{\infty} e^{-(x - x_4)^2/2c^2} dx = c\sqrt{2\pi} \tag{6}$$

Let A_2 be the area below the parabola between x_p and x_q.

$$A2 = \int_{x_p}^{x_q} \sqrt{4a(x - x_1)}\, dx = \frac{4\sqrt{a}}{3} \left[(x_q - x_1)^{3/2} - (x_p - x_1)^{3/2} \right] \tag{7}$$

Let A be the area enclosed by the Gaussian function and the parabola between x_p and x_q.

$$A = A_1 - A_2 = c\sqrt{2\pi} - \frac{4\sqrt{a}}{3} \left[(x_q - x_1)^{3/2} - (x_p - x_1)^{3/2} \right] \tag{8}$$

The parameter A represents the level of difficulty of an app. If $A=0$, then we say that the app is too easy for children. If $0 < A \leq 3.5$, then we say that the app is suitable for children. If $A > 3.5$, then we say that the app is too difficult for children.

3. Validation of the Model

3.1. Parameter a. We identified the important skills required by children to operate smartphones from the literature and calculated the value of the parameter a for these skills using Equation (2) (Table 1). Children need to hold a smartphone firmly in their hands in order to operate it. Some children are able to hold a smartphone properly in their hands at around eighteen months of age while the remaining children can do so by two years of age [7]. The value of the parameter a was found to be 0.5 for the skill of holding a smartphone firmly. Children learn to acquire stationary and moving targets on the screen of a smartphone between two and four years of age [16] and the value of the parameter a was found to be 0.125. Children learn to perform single-finger touchscreen gestures between two and five years of age [8, 17] and two-finger touchscreen gestures between seven and ten years of age [10]. The value of the parameter a was found to be 0.083 for both the skills. Children are able to follow non-textual and textual information provided by apps by seven and nine years of age, respectively [10]. The value of the parameter a was 0.083 and 0.125 for the two skills, respectively. Some children can use complex menu systems and navigate hypertext by nine years of age while the others can do so by eleven. The value of the parameter a was 0.125 for both the skills. Children become able to use augmented reality software between seven and ten years of age [13] and the value of the parameter a for the skill was 0.083. We found that the difference between the age at which some children acquire a skill and the age at which all children acquire it was typically two to three years, *i.e.* $0.075 < a < 0.125$ for most of the skills. Figure 2 shows the parabolic curves for the different skills.

3.2. Parameters c and A. We identified some smartphone apps that are used by children (Table 2). We calculated the values of the parameters c and A for these apps using Equation (5) and Equation (8), respectively, and thus determined their applicability and suitability (Table 3). For example, Baby's Fish is a simple game that requires acquiring on-screen targets and found interesting by children aged two to six years. The value of the parameter c was found to be 0.932 and the value of the parameter A was found to be 1.869 for this app. These values indicate that it is a niche app and suitable for two to six year old children. Baby's Butterflies app is similar to Baby's Fish except for the fact that the former uses augmented reality [13]. The app is not a niche app and too difficult for many children aged two to ten years who are interested in using it. We studied the applicability and suitability of two drawing apps, *viz.* Baby's Drawing and Sketch – Draw and Paint. The value of the parameter c was found to be 0.932 and 2.796 for the two apps, respectively, and the value of the parameter A was found to be 1.286 and 6.448 of the two apps, respectively. These results imply that Baby's Drawing is a niche app of suitable level of difficulty while Sketch – Draw and Paint is

Table 1: Skills required to use smartphone apps.

Skill	x_1	x_2	a
Holding a smartphone firmly in hand	1.5	2	0.500
Acquiring on-screen targets	2	4	0.125
Performing single-finger gestures	2	5	0.083
Performing two-finger gestures	7	10	0.083
Following non-textual prompting techniques	4	7	0.083
Following textual prompting techniques	7	9	0.125
Using complex menu system	9	11	0.125
Using augmented reality	7	10	0.083
Navigate hypertext	9	11	0.125

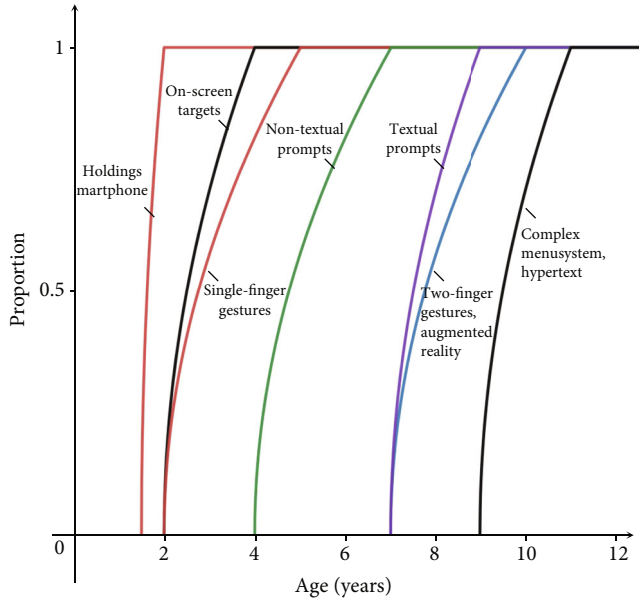

Figure 2: Plots for the skills required by children to operate smartphones.

too difficult for children who are interested in using it. Kid English Vocabulary is used by children aged four to eight years to learn novel words and their spelling and pronunciation. We found the app to be a niche app and easy for the children in the specified age range. Similarly, children find YouTube Kids, Google app and WhatsApp easy to use. However, these apps are used by children of a wide age range and, hence, are not niche apps. Wikipedia app requires children to be able to navigate hypertext. The app is used by children aged seven years and more. Since the value of the parameters c and A are 1.864 and 3.339, respectively, the app is not a niche app but of suitable level of difficulty. Figure 3 shows the plots of the Gaussian functions for these apps.

4. Discussion

4.1. Relevance of the Level of Difficulty. Children prefer smartphones over other digital devices because of their narrow gulf of execution. Children should possess sufficiently developed motor skills and expressive abilities to enjoy an immersive experience while using smartphone apps [18]. However, many of the smartphone apps developed for children do not take into account the psychomotor abilities of the children. If children do not possess the skills required to use an app, then they find it difficult to use. Children typically ignore apps they find difficult to use even though they are interested in their contents. For example, children younger than seven years cannot use augmented reality software and are not fond of games that use augmented reality [13].

The target age group should be first identified when developing an app [19]. It should then be ensured that using the app requires only the skills that children of the target age group possess [20]. Children are thrilled by apps that require the skills they have acquired recently. For example, seven to ten year old children find drawing apps with the pinch and zoom feature enticing. Ideally, the value of the parameter A should be between 0 and 3.5 for apps meant for children.

If using an app does not require the skills that the children have acquired lately, then they find that app too easy and look for more challenging apps. However, children do use easy apps if their contents are refreshingly new [21]. For example, children like to watch new videos on YouTube Kids although its interface is too simple.

4.2. Relevance of Niche Apps. In this study, we analyzed two drawing apps, *viz.* Baby's Drawing and Sketch – Draw and Paint. Baby's Drawing is a simple drawing app with limited features developed specifically for a narrow age range of children. Alternatively, Sketch – Draw and Paint is a professional quality drawing app with sophisticated features that can be used by users of all ages. Children like to draw with apps [7]. They can scribble and draw with Baby's Drawing and rarely complain about the paucity of features in the app. On the other hand, children get distracted by the multiplicity of features in Sketch – Draw and Paint. They do not know which features to use and get frustrated when they are unsuccessful in using a feature that requires advanced skills. We recommend the development of niche apps for children. Such apps may be designed specifically according to the abilities and interests of children of a particular age group. The value of the parameter c should ideally be less than or equal to 1 for apps meant for children. Different versions of the same app may be developed for children of different age groups, if necessary. For example, drawing apps of increasing sophistication may be developed for children aged two to six years, seven to ten years and older children.

4.3. Utility of the Work. The model can be used to identify niche apps and apps of suitable difficulty level for children of different age groups. The model will also help software developers to understand the relationship between the ability of children to use smartphone apps and their interest in actually using those apps, and thus help in the development of apps that are better suited for children.

4.4. Limitations. The model covers only smartphone apps and does not cover other digital contents accessed by children. A more comprehensive model taking into consideration children's interaction with different type of digital

Table 2: Details of the apps.

App	Description of the app	Most important skill required to use the app	Link from where the app can be downloaded
Baby's fish	A simple game where children have to tap on virtual fishes moving across the screen.	Acquiring on-screen targets	https://play.google.com/store/apps/details?id=com.bhavya.fishfishfish
Baby's drawing	A drawing app with minimal features and voice prompts.	Performing single-finger gestures	https://play.google.com/store/apps/details?id=com.india.apkcrew.babysdrawingapp
Sketch – Draw and paint	A drawing app with many features and options.	Using complex menu system	https://www.apkmirror.com/apk/sony-mobile-communications/sony-sketch-draw-paint/sony-sketch-draw-paint-9-0-t-0-0-release/sony-sketch-draw-paint-9-0-t-0-0-android-apk-download
Baby's butterflies	An augmented reality game where children have to tap on virtual butterflies flying across the screen with the live surrounding visible in the backdrop.	Using augmented reality	https://play.google.com/store/apps/details?id=com.nsit.baysbutterflies
YouTube kids	A video streaming app with content specially selected for children.	Holding a smartphone firmly in hand	https://play.google.com/store/apps/details?id=com.google.android.apps.youtube.kids
Kid English vocabulary	A vocabulary app that shows images of various objects and also provides their name, spelling and pronunciation.	Acquiring on-screen targets	https://play.google.com/store/apps/details?id=englishkideyelevel.ekel
Google app	An internet search app that supports searching with both textual and voice-based queries.	Holding a smartphone firmly in hand	https://play.google.com/store/apps/details?id=com.google.android.googlequicksearchbox
WhatsApp	An instant messaging app with support for audio and video calls.	Holding a smartphone firmly in hand	https://play.google.com/store/apps/details?id=com.whatsapp
Wikipedia app	An online encyclopaedia app.	Using hypertext	https://play.google.com/store/apps/details?id=org.wikipedia

Table 3: Applicability and suitability of the apps.

App	Parabola			Gaussian function			Intersection			Applicability	Level of difficulty
	x_1	x_2	a	x_3	x_4	c	x_p	x_q	A		
Baby's fish	2	4	0.125	2	4	0.932	3.500	4.000	1.869	Niche app	Suitable
Baby's drawing	2	5	0.083	2	4	0.932	3.038	4.431	1.286	Niche app	Suitable
Sketch – Draw and paint	9	11	0.125	2	8	2.796	9.000	10.123	6.448	—	Difficult
Baby's butterflies	7	10	0.083	2	6	1.864	7.000	7.977	4.301	—	Difficult
YouTube kids	1.5	2	0.500	2	8	2.796	8.000	8.000	0.000	—	Easy
Kid English vocabulary	2	4	0.125	4	6	0.932	6.000	6.000	0.000	Niche app	Easy
Google app	1.5	2	0.500	4	8	1.864	8.000	8.000	0.000	—	Easy
WhatsApp	1.5	2	0.500	2	8	2.796	8.000	8.000	0.000	—	Easy
Wikipedia app	9	11	0.125	7	11	1.864	9.000	11.000	3.339	—	Suitable

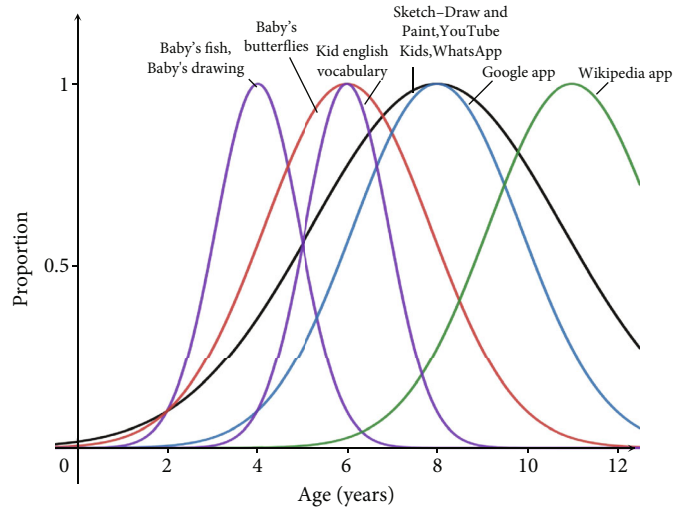

Figure 3: Plots for the interest of children about the apps.

devices will be more helpful in developing apps and other digital resources for educating and entertaining children.

5. Conclusion

We have developed a mathematical model for the ability and interest of children to use smartphone apps. The model can be used to determine the level of difficulty of apps. An app developed for a particular age group should require the skills that the children in that age group have acquired recently. Children get frustrated if an app is too difficult to use. Children are also not fond of apps that are too easy to use. The model can also be used to identify niche apps that are customized according to the interest of a narrow age range of children. We recommend that children be provided with niche apps of suitable difficulty level.

Data Availability

The paper is mathematical in nature and no empirical data has been used.

Conflicts of Interest

The author(s) declare(s) that they have no conflicts of interest.

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