A Framework of Touchscreen Interaction Design Recommendations for Children (TIDRC): Characterizing the Gap between Research Evidence and Design Practice

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ABSTRACT

HCI researchers have established a number of evidence-based design recommendations for children's touchscreen interfaces based on developmental appropriateness. Yet, these recommendations are scattered within the academic literature and lack a cohesive framework that makes them accessible to app designers. We created a framework of actionable Touchscreen Interaction Design Recommendations for Children (TIDRC, "tide-rock") by conducting a comprehensive review of the relevant literature. We used our TIDRC framework as a lens to empirically evaluate whether these evidence-based design recommendations were implemented within 50 popular iPad apps designed for children. We found a significant gap between research and practice. On average, only 63% of these apps followed design recommendations for meeting children's cognitive (51%), physical (67%), and socio-emotional (72%) needs. We characterize the nature of this gap and discuss opportunities for closing it when designing mobile touchscreen interfaces for children.

CCS CONCEPTS

• Human-centered computing ~ Interaction design

KEYWORDS

Children; touchscreen interfaces; interaction design.

1 INTRODUCTION

Since the commercial rise of touch-enabled devices and virtual app marketplaces such as Apple's iOS App Store, there has been a drastic increase in the use of touchscreen interfaces by children for games and educational purposes [53,73,74]. According to a 2015 US survey, 90% of toddlers had used a touchscreen by the age of 2 [38], and 73% of children (ages 5 to 12) report that they regularly use a tablet [75]. In some schools, parents are urged to purchase touchscreen devices in lieu of textbooks [74]. Yet, the developmental appropriateness of software has a significant impact on children's learning, and using software that is not developmentally appropriate can have a detrimental effect on children's creative skills [76]. Further, HCI and IDC research has shown that interface design strongly influences children's interaction experiences with touchscreen apps [1,17,24,72]. Therefore, it is important that apps meant for children are designed to their unique developmental needs, including information design, appearance, and input methods [17].

A number of HCI researchers (e.g., [1,5,17,23,24]) have conducted empirical user studies to understand how children interact with touchscreen interfaces and have recommended guidelines for better meeting the cognitive, physical, and socio-emotional needs of children. For example, Druin et al. [23] suggested that interfaces for young children should be highly visual, avoiding text as much as possible, to reduce cognitive load. Unfortunately, such evidence-based design recommendations for children's touchscreen interfaces are often scattered within the academic literature, making them less accessible to developers [19,48], who are the ones building the touchscreen apps children are using. Therefore, it is uncertain how well these evidence-based guidelines are translated into design practice. As such, we pose the following research questions:

RQ1: How can we synthesize evidence-based design recommendations for children's touchscreen interfaces?

RQ2: Is there a gap between research and practice for touchscreen interface design for children, and if so, how can we characterize its nature?

RQ3: If this gap exists, how can we work towards closing it?

To answer these questions, we conducted a comprehensive literature review of the empirical research on interaction design for children's touchscreen use. We used this meta-analysis to create a conceptual framework of Touchscreen Interaction Design Recommendations for Children (TIDRC, "tide-rock") for children ages 2 to 11. To synthesize the research into our framework (RQ1), we used a grounded approach [61] to identify 57 evidence-based design recommendations that researchers suggested for designing touchscreen interfaces for children. We conceptually group these recommendations based on children's unique **cognitive**, **physical**, and **socio-emotional** abilities [77] and note the developmental stage [51] (i.e., pre-operational in ages 2 to 7, concrete operational in ages 7 to 11, or both stages from ages 2 to 11) for which each recommendation should apply (Appendix A). We then used our TIDRC framework as a lens to empirically evaluate the interface design dimensions of 50 popular free iOS

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learning and entertainment apps for children to compare current interface design practices with evidence-based design recommendations from the literature.

Overall, we found a substantial gap between research evidence and design practice for mobile touchscreen interfaces for children (RQ2). On average, only about 63% of the apps followed design recommendations for meeting children's cognitive (51%), physical (67%), and socio-emotional (72%) needs. We also identified a lack of literature that included design recommendations for supporting children's socio-emotional development when using touchscreen interfaces. We use our TIDRC framework to discuss implications of these results in terms of bridging research and practice in the design of future touchscreen apps (RQ3). We make the following key contributions to HCI and IDC research and practice:

- Developed a *conceptual framework* of evidence-based design recommendations for children's touchscreen interactions based on their developmental needs.
- Conducted an *empirical analysis* of iOS apps to better understand how real-world interface design practices map to these evidence-based design recommendations.
- Characterized the *research-practice gap* our analysis revealed, by noting interface design dimensions under-studied in research, or research findings under-represented in real-world design, and suggested *actionable strategies* to bridge this gap.

Our work is a first step toward closing the gap between research evidence and design practice for touchscreen interfaces for children. We will disseminate the TIDRC framework publicly on the web, both to allow other researchers to extend our framework, and to reach the broader design community. Thus, our work will directly benefit application designers and developers who are creating touchscreen interfaces for children.

2 RELATED WORK

We motivate the TIDRC framework, and synthesize existing work that evaluates children's commercial touchscreen apps.

2.1 Frameworks for Interaction Design

Conceptual frameworks can serve as *boundary objects*, that is, objects that are shareable across domains, and thus function as a means to bridge gaps between disparate communities [28]. A number of interaction design frameworks have been created to synthesize specific areas of HCI research that have reached a maturation point. For instance, Ullmer and Ishii [64] proposed a framework in which they present an interaction model and key design characteristics for tangible user interfaces (TUIs). Prior work has also developed interaction design frameworks specific to children, which are grounded in child-specific developmental theories and the HCI literature [3,54,55]. For example, Rogers et al. [55] developed a conceptual framework for mixed reality specifically tailored towards children. Antle [3] proposed the Child Tangible Interaction (CTI) framework for the design of TUIs which support the cognitive development of children. Such research frameworks are important as they are commonly adopted among practitioners, who may not have been aware of all the disparate research on these topics [28].

The SIGCHI and IDC research communities have been at the forefront of demonstrating how children's developmental needs and abilities affect their interactions with touchscreen interfaces (e.g., [1,6,23,24,36]). However, this research has not yet been synthesized into a cohesive interaction design framework. Bekker and Antle [9] created developmentally-situated design (DSD) cards that make age-appropriate information about children's developmental abilities easily accessible to designers. However, they stop short of providing specific interface design guidelines to support those abilities. The closest example we found is the Haugland Developmental Software Scale (1999) [31,32], which evaluates mouse-driven software and websites for developmental appropriateness using criteria such as scaffolded complexity, non-violence, clear instructions, and child control. However, with the rise of tablets and smartphones, children have moved away from using mouse-driven computer interfaces to direct-touch interfaces [38]. While some of the same criteria will apply in this context, there are many new interaction design paradigms in use for touchscreens. Thus, the first goal of our work is to create a conceptual framework for the domain of touchscreen interface design for children based on research from the SIGCHI, IDC, and broader research community in this context.

2.2 Evaluating Children's Touchscreen Apps

Researchers have also recognized the need to critically examine interface design practices employed by commercial touchscreen app designers [24,60,65,69]. For example, Watlington [69] classified children's apps available on the iOS App Store using the Haugland Developmental Software Scale [31,32]. She reported that only 48% of the 108 apps analyzed were developmentally appropriate for educational use. The Joan Ganz Cooney Center at Sesame Workshop [65] conducted an analysis of literacy apps in the iOS, Google Play, and Amazon App Stores. They analyzed app descriptions and content to understand what children are likely to encounter when they use the apps. They found most of the apps did not give enough guidance and feedback while children interacted with them. Because of these design limitations, children might have difficulty learning the content as intended [24].

At CHI 2018, Benton et al. [10] presented an analysis of how interactive feedback was incorporated into five widely-used learning games for young children, based on the empirical literature on feedback and learning games. They found that game developers did well in delivering feedback when players succeeded, but feedback support was lacking for teaching new learners the mechanics of how to play the game. Papadakis et al. [49] examined eleven Greek educational apps for preschoolers and found that most apps promoted rote learning instead of deeper conceptual understanding of the learning concepts. These examples show the value that an evidence-based conceptual research framework can offer in evaluating the effectiveness of commercially available apps for children. However, all of these examples focused only on children's *cognitive* needs (e.g., interactive feedback, child control) from a learning sciences perspective. Therefore, we build upon and extend this work by creating a comprehensive theoretical framework of touchscreen interaction design recommendations for children (i.e., TIDRC), including three categories: children's **cognitive**, **physical**, and **socio-emotional** needs, when using both educational and entertainment touchscreen apps. Therefore, our contribution is specific to the fields of HCI and IDC, not learning sciences. We also use our framework to empirically evaluate a larger sample (50) of touchscreen apps than has been examined in past research.

3 DEVELOPING THE TIDRC FRAMEWORK

Our research team is composed of experts in child-computer interaction, touchscreen interaction research, qualitative research, and user experience. We conducted this research in multiple stages: from February to March 2016, we created the initial version of TIDRC based on 20 papers, identifying 32 design recommendations. Next, we conducted our empirical analysis of iPad apps from April to May 2016. We then iterated to add 11 new papers to the TIDRC framework from October 2017 to December 2018, for a total of 31 papers and 57 design recommendations. We followed a similar approach to developing the TIDRC theoretical framework as was first used by Roskos et al. [56] in the context of e-books. To identify relevant literature, we conducted keyword searches using Google Scholar and Elsevier with the following terms: "interface design for children," "touchscreen interfaces for kids," "guidelines for children's technology," and "children's interface design." The main criterion for inclusion was that the peer-reviewed research included an empirical user study of children (under age 12) in which design recommendations were formulated (i.e., "evidence-based"). We also included literature that synthesized other empirical work to propose guidelines for improving children's experience with technology (e.g., [16]). We then cross-referenced citations within the articles identified in our search to identify other relevant articles that met our criteria. Our goal was to cover a wide range of interface design dimensions beyond what had been examined in previous work. Papers that focused specifically on children with disabilities were excluded (e.g., [39]) from this version of the framework because of the substantial difference in design principles for this group [70].

The first author read each paper to interpret the empirical evidence and extract design recommendations. For example, Aziz et al. [6] documents that "children [ages 2 to 4] found it difficult and got confused when using gestures on crowded interface design" [p. 725]; we translated this finding into an actionable design recommendation: "avoid using visually complex application backgrounds as children can get confused when interacting on them" (B5, Appendix A). Some recommendations were supported by multiple articles, while some articles produced multiple recommendations. Therefore, the TIDRC framework includes 57 unique design recommendations across all 31 articles. We used an iterative, consensus-building process to categorize these recommendations into 19 interface design dimensions (bulleted in Table 1 in bold) and seven higher-level categories based on the interface features affected (underlined and italicized in Table 1). For example, both *on-touch events* and *feedback methods* are interface design dimensions that are related to ***application responsiveness*** because they reflect how the application responds to users' actions. Finally, we mapped these

Cognitive	***Visual Design Features*** • **Graphics:** abstract signs/symbols, real-world interactive objects, on-screen interactive cartoon characters. • **Application Background:** high graphics or low graphics. • **Text Font Size:** <0.5 cm, 0.5-1 cm, 1-2 cm, >2 cm.
	Audio Features • **Types of Sound:** narrative-sound elements, sound effects, background music.
	Interactive Features • **Clickable Items:** contrasting contour lines, broader color palette, animated. • **Menu Complexity:** present or absent. • **Interaction Prompts:** static or animated visuals, audio, visual + audio, none. • **Labels:** textual, audio, both, none.
	Application Responsiveness • **On-Touch Events:** sound, movement, vibration, none. • **Feedback Methods:** visual, verbal, points, none.
	Informational Features • **Tutorials:** present or absent. • **Instruction Format:** visual, audio, both, none. • **Advertisements:** present or absent.
Physical	***Gesture and Target Features*** • **Type of Gestures:** tap, drag/drop, scroll, zoom, pinch, rotate. • **Gesture Family:** multi-touch gestures, real-world gestures. • **Target Size:** visually bigger than non-interactive items.
Socio-Emotional	***Contextual Features*** • **Customization:** customization of background, avatar/character, music, none. • **Activity Structure**: open-ended, stages unlock after a criterion, the user selects the difficulty level. • **Social Sharing and Privacy**: present or absent.

Table 1. TIDRC framework grouped by developmental category. Codebook dimensions are bolded, followed by coded values.

seven categories to the cognitive, physical, or socio-emotional dimension, based on the child development literature [77]. We also noted the age range of children for which each recommendation was empirically validated by leveraging Piaget's four stages of child development [51]. The recommendations applied to ages 2 to 11, with 86% falling within the preoperational stage of development (ages 2 to 7), 31% in the concrete operational stage (ages 7 to 11), and 26% across both stages (e.g., ages 2 to 11). Some recommendations spanned partial stages and were double counted (e.g., ages 5 to 10). We include the full TIDRC framework in Appendix A; starred recommendations denote ones that were added in the second iteration. Next, we describe how we used this framework to conduct an analysis of a sample of 50 iOS apps.

4 ANALYSIS OF CHILDREN'S IPAD APPS

We followed a three-phase process to conduct our analysis: we (a) identified a set of 50 iOS apps using a critical case approach [50]; (b) iteratively generated qualitative codes based on the dimensions in the TIDRC framework; and (c) downloaded and explored each app to code the features (Table 1).

4.1 Selecting iPad Apps for Empirical Analysis

We followed a systematic approach to select a representative subset of apps to evaluate. The iOS App Store has a specific "Kids" category for children [78]. Since the majority of the apps in the

"Kids" category belonged to Education (60%) or to Games (47%) [78], we focused on these two sub-categories. We included both learning and entertainment apps in our analysis because the TIDRC design recommendations are not tied to learning directly, but instead are related to fundamental aspects of children's cognitive, physical, and socio-emotional skills that apply when interacting with any app. We selected a set of 150 free apps from the Kids category top charts in the "Education" and "Games" sub-categories between March and April 2016. Next, we filtered the apps by inclusion criteria designed to identify the most-used apps targeted at the intended audience: 1) We removed apps with fewer than 500 user ratings. 2) We read app descriptions to ensure that they were not intended to be used with the guidance of an adult. 3) Apps that specifically focused on children with disabilities were excluded because of differences in design guidelines for this group [70]. Our final dataset included 50 apps.

The 50 children's apps in our dataset were published by 34 unique developers, ranging from large companies, like Disney and Toca Boca Ab, to independent developers. Based on the age designations specified for the apps, the target age groups for these apps were: 5 and under (58% of apps), 6 to 9 (28%), 9 to 11 (10%), or not specified (4%). The apps spanned a mix of games (56%) and educational (44%) apps. Educational apps included storytelling apps or apps to teach children how to write the alphabet. Some of the game apps we analyzed were designed simply for entertainment such as makeup games [79] and racing games [80]; on the other hand, some game apps in our dataset specifically mentioned learning as their main goal in the app description.

4.2 Applying the TIDRC Framework

To analyze these apps based on our TIDRC framework, we first generated a codebook that mapped our first version of TIDRC (not including starred design recommendations in Appendix A) to interface features. The same interface features could have been coded as supporting multiple design recommendations. For example, **types of gestures** (43-49) is a set of recommendations about what gestures to support based on studies that identified physical difficulties children had with certain gesture types. **Interaction prompts** (22-24) are about what gestures to support based on studies that focused on cognitive aspects of children understanding what gestures to do. The codebook consisted of (a) a name and description of each coding dimension, and (b) a visual illustration of each dimension, e.g., screenshot(s) from the sample apps. Using an open-coding approach [37], our team first examined five randomly chosen children's apps from our sample to generate coding values for each interface design dimension in our codebook. Then, based on another sample of 10 randomly chosen apps, the research team worked together to come to a consensus on the codebook dimensions, codes, and their descriptions. The first author used this refined codebook (final codebook, Table 1) to code all 50 apps in our dataset.

All the apps were downloaded and analyzed using an iPad Mini 16GB (model #A1432), iOS 9.2.1. This model has a 7.9" color screen and 1024 x 768 display resolution (163 ppi). Each value for each interface design dimension was coded as a binary value to reflect whether the value was present or not (i.e., "yes" or "no"). The team explored all the features and screens of each app during coding. Apps could contain both positive and negative, or multiple independent, examples of each recommendation. For instance, an app could have both animated and static interaction prompts, such as on different screens or in different parts of the same screen. Also, in an app that made a "click" sound on tapping, both the **on-touch events** and **types of sound** were coded as "present".

5 RESULTS OF EMPIRICAL APP ANALYSIS

In Figure 1, we illustrate the overall number of apps we analyzed that were consistent with our TIDRC framework (dark bars). On average, only about 63% of the apps followed recommendations for meeting children's **cognitive** (51%), **physical** (67%), and **socio-emotional** (72%) needs. For example, only 40% of the 50 apps (i.e., 20 apps) adhered to recommendations related to **graphics**, but 74% of the apps followed guidelines for **types of gestures**. Next, we define our framework dimensions in relation to the detailed empirical analysis.

5.1 Cognitive Abilities

Cognitive abilities include the intellectual growth of a child, which affects skills such as attention, understanding, and reading [17,21,63]. Table 2 maps each recommendation related to

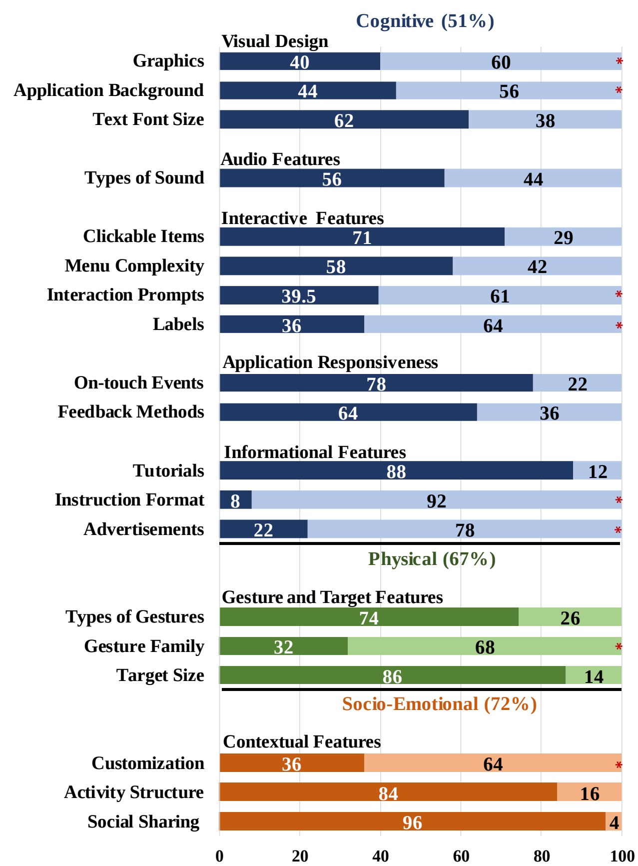

Figure 1: Dark bars show the average % of apps in our sample that comply with TIDRC design recommendations, grouped by developmental category. Starred (*) dimensions indicate more than 50% of apps did not comply with the recommendations.

cognitive abilities with an indication of direction (e.g., *use* or *avoid*) to the coded dimension from our analysis. The coded dimensions are presented in the same order as in the TIDRC framework (Appendix A). We also use this structure in Tables 3 and 4 to present results for physical and socio-emotional abilities.

5.1.1 Visual Design

Visual design features (e.g., aesthetics, graphics) are important as they influence children's understanding of the functionality of interface components [13,35].

Graphics. The majority of the apps (60%) in our sample used an on-screen cartoon character that interacted with children, as recommended (G3, Appendix A) [17,24]. Over half of the apps (58%) used images of real-world objects, such as a cookpot, so that children could apply their real-world knowledge of how to interact with them in the app (i.e., stirring) (G1) [6]. However, only 2% of apps adhered to the guideline to avoid using abstract signs and symbols (e.g., pause/play symbols), despite the fact that linking a symbol to its meaning is difficult for children (G2) [35].

Application Background. Aziz et al. [6] found that children get confused when using gestures in a crowded interface design. We coded apps in our sample for the presence of either "high graphics" or "low graphics" backgrounds (B5). The use of intricate details in an app's background (not necessarily interactive) was categorized as "high graphics." For example, *Letter Quiz School Reading, Spelling and Tracing Educational Program* [81] uses a garden-themed background with birds and flowers. In contrast, *Toca Boca Kitchen*'s [82] interface with a plain gradient background was considered to be "low graphics." Less than half (44%) of apps were consistent with this design recommendation.

Text Font Size. Design recommendation F7 emphasizes that designers should use a minimum of 14-point text font size (0.5cm), to increase legibility for early readers [11]. We measured vertically in centimeters the different font sizes used in apps for labels, headings, or textual instructions. 62% of the apps followed this recommendation and avoided font sizes smaller than 0.5cm.

On average, the majority of the apps in our sample used appropriate **text font sizes** (62%). However, less than half of the apps properly met children's cognitive needs related to **graphics** (40%) and **application background** (44%) (Figure 1).

5.1.2 Audio Design

Audio features consist of auditory components (i.e., sounds) of the application. Young children are still developing their reading skills; therefore, audio cues are more appropriate for conveying information for children than text [23].

Types of Sound. Design recommendation S12 emphasizes using audio features such as sound effects and vocalizations to help direct a child's attention towards important content for learning purposes [16,26]. Nearly all apps (90%) in our sample used some kind of sound effect for these features (S12). In addition, over half of the apps (58%) used narrative-style sound elements to help foster children's language development (S11) [43,65]. While prior work suggests using background music to enhance engagement [58], doing so for children under age 5 can overload them by requiring them to simultaneously process interface content and music (S10) [16,58]. Not many apps (20%) followed the design guideline of avoiding using background music for this age. Overall, over half (56%) of the apps applied design recommendations about **types of sound** consistently (Figure 1).

Cognitive Dimensions	Design Recommendations	Apps (N= 50)
Visual Design Features		
Graphics	G1: Use consistent real-world metaphors	29 (58%)
	G2: Remove abstract signs and symbols	1 (2%)
	G3: Use on-screen interactive cartoon characters	30 (60%)
Application Backgroun d	B5: Avoid using visually complex application backgrounds	22 (44%)
Text Font Size	F7: Use a minimum of 14-point font size	31 (62%)
Audio Features		
Types of Sound	S10: Do not use background music with videos	10 (20%)
	S11: Use narrative-style sound to foster language development	29 (58%)
	S12: Use sound effects and vocalizations to draw attention	45 (90%)
Interactive Features		
Clickable Items	CI13: Visually differentiate clickable items from the rest of the screen	42 (84%)
	CI16: Limit the behavior of clickable items to their sole purpose	29 (58%)
Menu Complexity	M17: Avoid using extensive menus in children's apps	29 (58%)
Interaction Prompts	I19: Use interaction prompts	27 (54%)
	I20: Avoid using textual prompts	34 (68%)
	I21: Provide audio prompts with visual prompts support	2 (4%)
	I24: Provide animated prompts for demonstrating gestures	16 (32%)
Labels	L27: Provide audio for text labels	18 (36%)
Application Responsiveness		
On-touch Events	TE28: Provide visual/audio feedback of accepted touch input	39 (78%)
Feedback Methods	FM30: Provide auditory feedback	23 (46%)
	FM31: Provide positive feedback	38 (76%)
	FM33: Avoid heavy emphasis on extrinsic rewards	35 (70%)
Informational Features		
Tutorials	T38: Avoid using in-app tutorials	44 (88%)
Instruction Format	IF39: Provide audio option to read aloud textual instructions	4 (8%)
Advertise-ments	A42: Avoid adding external web links or advertisements	11 (22%)

Table 2: Summary of app coding for Cognitive Abilities (red shading denotes recommendations not followed by >50% apps).

5.1.3 Interactive Features

Interactive features consist of interface elements used in an app to prompt user input, and are important because they encourage active engagement versus passive consumption [83].

Clickable Items. Apps used various visual methods to help "clickable items" stand out to let users know they were interactive, as recommended (CI13) [26,58,66]. Examples include using a different color scheme for clickable and non-clickable items (34%), or dark contour lines around the clickable items (84%). Prior research recommends limiting the behavior of interactive elements to their sole purpose by avoiding extraneous animations or sounds (CI16) [26], because if an item animates, children tend to believe the animation is the sole functionality and are less likely to tap on it. Most of the apps (58%) followed this guideline and did not use clickable items that continuously animated to attract attention. On average, the majority of the apps (71%) were consistent with guidelines for clickable items (Figure 1).

Menu Complexity. Design recommendation M17 suggests avoiding using extensive menus in children's apps, as children may not yet have the knowledge required to navigate efficiently [17,23]. Hierarchical menus are not very common in mobile applications and are often translated into a button that gives further access to other buttons [84]. We coded apps for the presence or absence of complex buttons that give the user access to modify multiple functional settings of the app, such as sound level or language preference. Over half of the apps (58%) in our sample were consistent with this recommendation and avoided including such complex multifunctional buttons (M17).

Interaction Prompts. Prompts are often present in apps to aid users in performing a task. Apps can use static visual (text) prompts or audio prompts consisting of in-app voice recordings. For children, audio or visual cues for prompting is recommended over using textual prompts, to reduce cognitive load [23]; most of the apps (68%) avoided using textual prompts (I20) [17,23,44]. Using interaction prompts helps in supporting a child's understanding of the app content (I19) [17,34]; 54% of the apps included interaction prompts to guide children during their interaction. Other research suggests that designers provide animated prompts for demonstrating gestures to children (I24) [34,44,66]. For example, *Kids ABC 3D Lite* [85] uses an animated cartoon image of an iPad appearing on the screen, in which two hands are gripping the iPad and repeatedly tilting it from side to side to give the appearance of the iPad shaking back and forth. Not many apps (32%) followed this recommendation (I24). Also, it is recommended to provide audio prompts with visual support, because children do not pay attention to audio prompts alone (I21) [24,29]; very few apps (4%) were consistent with this guideline. Although over half of the apps (54%) provided prompts, on average only 39.5% of the apps were consistent with the guidelines for designing interaction prompts in a developmentally appropriate format (Figure 1).

Labels. Labels can be textual, for example, a book icon on the screen accompanied by the word "Books," or auditory, such as an audio label attached to a car that calls out "This is a car" when the user taps on it. 68% of the apps in our sample contained textual labels, but not many apps (36%) contained audio labels with the text as is recommended for children (L27) [24,29].

Most apps followed guidelines for **clickable items** (71%) and **menu complexity** (58%). Less than half designed **interaction prompts** (39.5%) and **labels** (36%) in ways suitable for children.

5.1.4 Application Responsiveness

Application responsiveness is important for giving feedback in response to a user's actions [83], especially in the touch modality [71]. Children can be impatient and expect to see the feedback of their actions immediately [17,71].

On-Touch Events. We analyzed the mechanism by which an app interface provides feedback and confirmation of the child's interactions. Design recommendation TE28 suggests providing visual and/or auditory feedback of accepted touch input [71], for example, giving immediately noticeable on-touch feedback using animations or sounds. Most of the apps in our sample did use sound (86%) or animation (80%) as a medium to provide on-touch feedback (TE28). Many apps (78%) used both sound and animation together to notify children of accepted input. On average, 78% of the apps were consistent with this design guideline.

Feedback Methods. Providing feedback on how to interact with an app's content is important for children to be able to interact successfully [24,45]. Prior work recommends providing encouraging positive feedback to motivate children (FM31) [24,45], especially in an auditory format such as applause sounds and appreciative phrases (i.e., "Great job!") (FM30) [24,45]. While 76% of apps provided feedback, less than half of the apps (46%) were consistent with the guideline to provide this type of audio feedback. Design recommendation FM33 suggests avoiding heavy emphasis on extrinsic rewards such as points because they may overshadow children's learning motivation [24,45]. Most apps (70%) in our sample did not provide extrinsic rewards (e.g., points), as recommended (FM33). On average, over half of the apps (64%) in our sample followed feedback guidelines (Figure 1).

Most apps gave confirmation of the user's **on-touch events** (78%) and over half of the apps (64%) designed **feedback** effectively targeted towards children's cognitive development (Figure 1).

5.1.5 Informational features

Informational features involve textual or audio commands to perform an action within the app, without detailed information about how something should be done, such as what gesture to use (**interaction prompts** focus on the *how*).

Tutorials. Tutorials are short demonstrations to teach a child how to use an app. Prior work suggests avoiding using in-app tutorials for children, because they will likely not read a manual or remember a tutorial to learn how to use an interface; the interface must provide active guidance through tasks (T38) [17]. Most of the apps (88%) in our sample did not include tutorials. However, this finding should be contextualized in relation to poor adherence to **instruction format** as discussed below, because generally apps did not provide active guidance for children at all.

Instruction Format. An instruction is a visual (textual) or auditory command indicating what to do next. It is important to communicate an app's objectives to children in a format that they can understand [17,24,36]. We saw that the majority of the apps in our sample (60%) provided instructions like **labels**. Prior research suggests always providing an option to have text instructions read aloud for children (IF39) [24]. We coded for the presence of textual instructions such as, "*Match capital case letters to small case letters,*" [86] or in-app audio instructions. We found

Physical Dimensions	Design Recommendations	Apps (N= 50)
Type of Gestures	TG43: Avoid using rotate gesture	47 (94%)
	TG43: Avoid using pinch to zoom gesture	46 (92%)
	TG43: Avoid using drag and drop gesture	28 (56%)
Gesture Family	GF51: Use gestures to manipulate objects in a consistent manner with the object's use in the real world	16 (32%)
Target Size	TS52: Design visually bigger interactive widgets	43 (86%)

Table 3. Summary for app coding for Physical Abilities.

that 36% of the apps used auditory instructions, and 32% of the apps used textual instructions. However, only 8% of the apps included both textual and audio instructions together (IF39).

Advertisements. Design guideline A42 recommends avoiding external web links or advertisements in children's apps [24,40]. Most apps (78%) in our sample included some advertisements, likely because our sample consisted of free iOS apps. However, including ads in children's free apps is a problematic design trend because children lack the skills needed to identify advertising and distinguish it from application content [24,40].

Although most of the apps were consistent with the guidelines for **tutorials** (88%), very few apps provided active **instructions** in a format easily understandable to children (8%). Also, not many apps (22%) avoided including **advertisements** (Figure 1).

5.2 Physical Abilities

Next, we summarize design trends for interface features that relate to physical abilities (Table 3).

5.2.1 Gesture and Target Features

Gesture and target features can impact a child's interaction with touch interfaces since motor abilities develop gradually over time [59,67], affecting manipulation of interface elements [67].

Type of Gestures. Children generally progress from being able to use tap gestures at ages 3 to 4 to more complex gestures such as pinch by ages 6 to 7 [5,66]. Therefore, age-specific motor limitations must be appropriately considered when choosing the gestures for touch interfaces [1,5,6,66,71]. Prior work found that children ages 2 to 4 years struggled to perform gestures like drag and drop, rotate, and pinch (TG43) [5,6,66]. For instance, a gesture like free rotate would require that children twist their fingers, and is difficult for children under age 4 [5]. The majority of the apps avoided using multi-touch gestures such as pinch to zoom in/out and rotate (TG43). However, almost half of apps (44%) included drag-and-drop, which violates this design guideline. For example, *Letter Quiz School Reading, Spelling and Tracing Educational Program* [86], designed for preschoolers and kindergarteners, asks users to match upper and lower-case letters using drag-and-drop.

Gesture Family. Design recommendation GF51 emphasizes that gestures to manipulate objects in children's apps should be consistent with the object's use in the real world [6]. For example, *Ice Cream Truck: A Crazy Chef Adventure* [81] lets children stir milk with a spatula by moving a finger in a circular motion on the screen. The majority of the apps we evaluated used standard touchscreen gestures (e.g., tap). However, not many apps (32%) followed this guideline to also use real-world gestures (GF51).

Target Size. Research suggests increasing the active area for icons to allow slightly out-of-bounds touches and to use visually bigger interactive targets for children to accommodate developing dexterity (TS52) [1,66,71]. Our findings show that the majority of apps (86%) were consistent with this recommendation.

On average, most of the apps met children's physical needs by consistently applying guidelines for **types of gestures** (74%) and **target size** (86%). However, not many apps (32%) followed the guidelines for **gesture family** (Figure 1).

5.3 Socio-Emotional Abilities

We now highlight design trends for features related to socio-emotional abilities (Table 4).

5.3.1 Contextual Features

Accommodating socio-emotional abilities includes *contextual features* to make children's experiences with technology more enjoyable in order to keep them engaged [72].

Customization. Design recommendation C54 suggests providing customization features to enhance children's motivation and engagement [22,33,57]. Customizable features include options available to users for changing the application background, music, and so on. On average, not many apps (36%) followed this recommendation. For example, 30% of the apps in our sample allowed children to choose the type of character, 4% for music, and 16% for the background image of the app (C54).

Activity Structure. Design recommendation AS55 notes that an open-ended activity structure, in which the app provides no explicit goals or tasks, can help increase children's engagement [42]. For example, *Barbie Magical Fashion – Dress Up* [79] allows children to dress up Barbie over and over again, with no increase in the level of difficulty. While prior research has suggested that a progressive activity structure that allows a child to advance from one level to the next and receive extrinsic rewards can increase engagement [29], doing so can also distract from their intrinsic motivation for learning [24,45]. The majority of the apps (84%) were consistent with this recommendation and used an open-ended activity structure (AS55). Very few apps asked children to select the difficulty level (e.g., beginner, expert) before playing (4%), or unlocked stages after the player earned a specific number of rewards (12%), in line with this recommendation.

Social sharing and privacy. Design recommendation S56 recommends avoiding computer-automated social interactions in apps for children ages 2 to 12 because it does not improve their engagement and motivation [18]. Most of the apps in our sample (96%) did not include social sharing features, e.g., sharing badges

Socio-Emotional Dimensions	Design Recommendations	Apps (N=50)
Customization	C54: Provide customization features	18 (36%)
Activity Structure	AS55: Use an open-ended app structure	42 (84%)
Social sharing and privacy	S56: Avoid automated social interactions	48 (96%)

Table 4. Summary for app coding for Socio-Emotional Abilities.

with other people. One reason for the large trend toward compliance here could be due to platform-specific guidelines about children's privacy [4], or the United States law called the Children's Online Privacy Protection Act (COPPA) [20].

The majority of apps consistently applied guidelines for **social sharing and privacy** (96%) and **activity structure** (84%). Not many apps (36%) followed **customization** guidelines (Figure 1).

6 DISCUSSION

Our intent is that the TIDRC framework will serve as a *boundary object* that synthesizes state-of-the-art research evidence into practical recommendations for interaction design of children's touchscreen applications (**RQ1**). As such, it is an example of creating and presenting *intermediate-level knowledge* [7] that has recently been emphasized in the child-computer interaction research community. Our framework can be used by interaction designers to *inform design decisions* when designing new apps and to *evaluate* existing or new children's touchscreen apps. It is worth noting that many TIDRC design recommendations are not touchscreen-specific (e.g., visual design features) and can also inform the design of future interfaces for children on other platforms. In creating the TIDRC framework, we found that some evidence-based design recommendations are conflicting and that there is a lack of research focusing on designing for the socio-emotional needs of children. Second, our empirical analysis of 50 popular iOS apps showed a practical application of the TIDRC framework and found that many evidence-based design recommendations are not well-translated into practice, which confirms and scopes the research-practice gap in this context that needs to be addressed (**RQ2**). We discuss the implications of this gap and potential ways we and other researchers might work to close it (**RQ3**).

6.1 Conflicting Guidelines

In constructing the TIDRC framework, we encountered some contradictory recommendations. We resolved these conflicts by erring on the side of caution in our interpretations by not recommending a feature if at least one study found that it may be problematic for some children. For example, in Nacher et al.'s study [47] with children ages 2 to 3, this age group could effectively perform multi-touch gestures like rotation. In contrast, in Aziz's study [5], children ages 2 to 4 had trouble with such complex gestures. Therefore, we recommended to avoid using complex multi-touch gestures, since they are not likely to work well for all children. Also, based on their observations of children (no age specified), Hanna et al. [29] recommended using subtle animation for interactive elements to indicate functionality. In contrast, Gelman's study [26] found that children ages 2 to 4 are less likely to tap on an animated element, so we recommended limiting animation of interactive elements. A third example is the recommendation to use an open-ended activity structure, in which an app provides no explicit goals or tasks, to help increase children's engagement [42]. Other studies offered conflicting guidelines that indicated providing goals can increase engagement by offering extrinsic rewards [29]. None of the studies directly compared open-ended to goal-based structures. These examples of conflicting evidence are important areas for future research to investigate to clarify and seek convergence.

6.2 Designing for Socio-Emotional Needs

In developing the TIDRC framework, we also identified that, while the cognitive and physical capabilities of children are well-studied, there is a significant lack of evidence-based design recommendations to support the socio-emotional needs of children. Although we did look at a broad sample of articles beyond touchscreen interaction design to build the TIDRC framework, only four out of the 57 recommendations (7%) we found focused on children's socio-emotional abilities. Yet, Hiniker et al. [33] showed that interface designs that accommodate children's socio-emotional abilities, such as planning and making intentional choices, can promote autonomy and scaffold media self-regulation. Therefore, we echo Chiasson and Gutwin's call to action [17] for more research in this space. In addition, we only focused on social interaction *within* the apps, but some apps are designed for parent-child dyad use, supported by developmental literature on learning with media [68]. Other research has examined children's socio-emotional needs while interacting with non-interactive media and characters [27]. Future work should consider how these areas of research can be applied to design in touchscreen contexts. Another potential explanation for the lack of research at the intersection of touchscreen interaction design for children and children's socio-emotional needs may be due to the disconnect between the social computing and novel interaction research communities within SIGCHI [12]. Technology-agnostic guidelines for addressing children's socio-emotional needs have been developed in research communities like CSCL [41], but they have generally seen slow uptake within the children's touchscreen interaction design community. Thus, we call for the social computing and systems research communities to work together toward this larger goal of holistic design for children's range of developmental needs.

6.3 Implications of the Research-Practice Gap

The SIGCHI community has been keen on the importance of identifying and closing research-practice gaps (e.g., [14,15,19]). In 2018, Beck and Ekbia called for more research to evaluate the broader HCI research-practice gap in order to effectively bridge theory and practice [8]. This gap diminishes the impact of HCI research and hinders practitioners from taking advantage of key insights from the SIGCHI research community [14,15]. Our work uncovers a substantial disconnect between empirical IDC research and the design of commercial touchscreen apps for children. Overall, we found that some guidelines were adhered to within the design of the apps in our sample, but more than half were generally ignored. For example, most of the apps successfully avoided using complex multi-touch **gestures** (94%) and designed large interface widgets (**target size**) to account for the limited dexterity of children (86%). These results indicate current designers have good awareness of children's motor abilities. On the other hand, not many apps (40%) adhered to cognitive design recommendations for visual **graphics** that suggest avoiding *abstract signs and symbols* that are difficult for young children to link to their referents [17,35]. Less than half of the apps (44%) followed design recommendations for **graphics** that suggest avoiding the use of visually crowded *application backgrounds* [6]. Only 8% and 39% of the apps, respectively, effectively applied cognitive design recommendations for **instructions** and **interaction prompts**. These design trends highlight how significant the research-practice gap is in terms of supporting children's cognitive needs. Without addressing this gap by making the relevant design guidelines accessible to app designers and developers, children's touchscreen apps may, at best, be abandoned for lack of ability to use them, and, at worst, hinder children's development by ignoring opportunities for design.

6.4 Recommendations for Bridging this Gap

As HCI researchers, how can we help bridge the research-practice gap and make sure design recommendations are easily accessible and usable by children's app designers? We enumerate potential solutions that can help address this challenge.

Leverage Conceptual Frameworks. Our TIDRC framework for designing touchscreen apps for children is rooted in evidence-based design guidelines generated by the SIGCHI and IDC research communities. We will share our TIDRC framework publicly via the web and invite the research communities to update this framework as new empirical evidence on children's touchscreen interfaces emerges. We also intend to iteratively refine the dimensions of our framework to make it useful for both researchers and practitioners, in collaboration with others.

Translate Research Findings into Actionable Design Guidelines. Academic writing styles can be perceived by practitioners as complex and abstract [15,25], which discourages practitioners from making use of academic findings [14,15,19]. Therefore, we call for researchers to focus on writing actionable recommendations using the vocabulary used by design practitioners, similar to what we do in our TIDRC framework (i.e., *use* and *avoid*) to make it more accessible to practitioners.

Disseminate Research Findings More Broadly. The evidence-based research in our framework or others will not be translated into design practice unless we engage with practitioners outside of our academic community. Therefore, we plan to, and recommend IDC researchers also, publish periodically in professional / practitioner venues, such as *UXPA Magazine*, the *SIGCHI Bulletin*, and the *CSCW Blog* [2,87,88]. We intend to disseminate the TIDRC framework through these channels to ensure broader reach. In addition, we encourage researchers to leverage bridging initiatives by participating in workshops, mailing lists, and public scholarship to connect academia, industry, and general audiences in this space.

7 LIMITATIONS AND FUTURE WORK

Our intention is that the TIDRC framework will be a living document that will continue to be updated over time. The TIDRC framework will need to be frequently updated as new empirical research on effective touchscreen design for children becomes available. Our empirical app analysis was conducted based on our first version of the TIDRC framework, which included 32 of the 57 design recommendations in Appendix A. After we conducted this analysis, we iterated on the TIDRC framework to add additional recommendations. While a substantial research-practice gap was confirmed by our representative empirical app analysis, additional gaps may be uncovered if evaluated based on new design recommendations. Therefore, our empirical app analysis is a starting point for bridging the gap between research evidence and design practice as opposed to the end point; it serves to validate the TIDRC framework by providing a benchmark sample of popular children's touchscreen apps in comparison to a subset of available evidence-based design recommendations.

The apps we chose for the empirical analysis were based on the free iOS top chart listings during March and April 2016, and the app landscape may have changed. Our sample also included more apps designed for younger children (under age 5) than other ages. Therefore, a comparison to new, for-pay apps, or apps designed for a broader age range of children would be useful to confirm whether the gaps we uncovered are generalizable to these contexts. This study only evaluated design trends for iOS, because it has the largest market share in the US [89]. Future work could analyze apps from different app stores to increase the external validity of our results. Correlating the success of apps (e.g., based on user ratings) with how well they followed or did not follow TIDRC recommendations would also be of interest for future work. An essential next step for this work is to link with app developers in order to understand the key reason for the research-practice gap in this space: is it access to the research-based evidence, or is it design constraints affecting their ability to use knowledge from research, or something else? Finally, we urge researchers to synthesize design guidelines and evaluate the accessibility of apps designed for a more diverse range of children, including those with disabilities.

8 CONCLUSION

We introduce the evidence-based Touchscreen Interaction Design Recommendations for Children (TIDRC, "tide-rock") framework, which we used to conduct an empirical analysis of 50 iPad apps for children to assess whether research-based design guidelines are being implemented in practice. Our TIDRC framework allowed us to identify gaps in practice, as well as open research questions in touchscreen interaction design for children. While most apps tried to accommodate children's physical abilities, there was a substantial disconnect between design practice and recommendations proposed to meet children's cognitive and socio-emotional needs. Based on these findings, we present implications for future researchers and designers to consider. We publicly release the TIDRC framework guide as a one-sheet download for researchers and practitioners to easily access at the following URL: https://init.cise.ufl.edu/tidrc/.

Interface Dimensions		Evidence-Based Design Recommendations Related to Cognitive, Physical, and Socio-Emotional Needs of Children
Cognitive		
Visual Design Features	Graphics (G)	1. Be consistent with images or graphical metaphors used in interfaces and their real world use [6]. **(ages 2-7)** 2. Remove visual embellishments from symbols to support children's limited capability for symbol-referent mapping [26,35]. **(ages 2-7)** 3. Use child-like on-screen characters as guides or pedagogical agents to improve learning outcomes [17,24]. **(ages 2-11)**
	Application Background (B)	4. *Avoid using interface designs with lots of different colors or shades [26]. **(ages 2-7)** 5. Avoid using visually complex application backgrounds as children can get confused when interacting on them [6]. **(ages 2-7)** 6. *Make foreground items of the interface clearer and more detailed than the background items [26,36]. **(ages 2-7)**
	Text Font Size (F)	7. Use a minimum of 14-point font size to help children read faster [11]. **(ages 7-11)** 8. *Avoid using Times font style as children report it to be significantly less easy to read [11]. **(ages 7-11)**
Audio Features	Types of Sound (S)	9. *Make sure that every sound used in the interface has a specific meaning and function [26]. **(ages 2-7)** 10. Avoid using background music with videos, especially for children ages 5 and under [16,58]. **(ages 2-7)** 11. Consider using narrative-style sound elements as they foster children's language development [43,65]. **(ages 2+)** 12. Use audio features (e.g., sound effects, vocalization) to draw attention to important content for learning purposes [16,26]. **(ages 2-7)**
Interactive Features	Clickable Items (CI)	13. Visually differentiate clickable elements from the rest of the screen, e.g., use different colors or dark outlines [26,58,66]. **(ages 2-7)** 14. *Avoid placing small interactive elements at the screen edges, especially in visually complex interface designs [71]. **(ages 2-11)** 15. Be careful when using animated hotspots to capture children's attention as they may distract from learning [62,65]. **(ages 2-11)** 16. Limit the behavior of interactive elements to their sole purpose, e.g., avoid extraneous animations or sounds [26,65]. **(ages 2-11)**
	Menu Complexity (M)	17. Avoid using hierarchical menus as young children may have difficulty navigating these successfully [17,23,36]. **(ages 2-11)** 18. *Provide a means to reverse children's actions in order to support their exploratory behavior [36]. **(ages 2-7)**
	Interaction Prompts (I)	19. Provide explicit scaffolding such as interaction prompts to help children remember how to accomplish tasks [17,34]. **(ages 2-11)** 20. Consider using audio or visual cues for prompting instead of using textual prompts [17,23,44]. **(ages 2-11)** 21. Provide audio prompts with visual support because children do not pay attention to audio prompts alone [24,29,65]. **(ages 2-7)** 22. *Choose the wording of prompting interactions to be less technical and more "kid-friendly" to understand [44]. **(ages 2-7)** 23. *Be careful when using touchscreen terminologies such as select, pinch, and zoom for children's interfaces [44,52]. **(ages 2-7)** 24. Provide animated prompts to help children learn what gestures to make, such as providing prompts for long-press gestures to help children remember to release their fingers after holding for a long time [34,44,66]. **(ages 2-7)** 25. *Keep essential audio, e.g., specific interaction suggestions, at the end of the sentence, not at the beginning [58]. **(ages 2-7)** 26. *Try utilizing time-outs after 3 to 5 seconds of inactivity to prompt children what to do next [58]. **(ages 2-7)**
	Labels (L)	27. Provide an option to have text labels (i.e., descriptions of on-screen objects and visual metaphors) read aloud [17,24,29]. **(ages 2-7)**
Application Responsiveness	On-Touch Events (TE)	28. Provide visual or audio feedback of accepted touch input; children benefit from larger, longer visual feedback [71]. **(ages 2-11)** 29. Use audio feedback to indicate accepted input to avoid distractions from unintended touches [17,29]. **(no age specified)**
	Feedback Methods (FM)	30. Provide auditory feedback such as an applause sounds or appreciation phrases during and after task completion [24,45]. **(ages 2-7)** 31. Provide effective scaffolding via positive feedback to motivate children, e.g., a character that encourages them [24,45]. **(ages 2-7)** 32. *Provide corrective feedback, such as pop-ups or dialogues offering feedback for correct and incorrect answers [10,24,30]. **(ages 2-7)** 33. Avoid heavy emphasis on extrinsic rewards such as points to not overshadow intrinsic learning motivation [24,45]. **(ages 2-7)** 34. *Provide feedback when app is busy processing so that children know to wait for something to happen [17,29]. **(no age specified)** 35. *Avoid using symbolic trackers like progress bars to track children's progress, especially for ages 4 and under [35]. **(ages 2-7)** 36. *Create a visual illusion to help children map a symbol to its referent [35]. **(ages 2-7)** 37. *Use synchronous text highlighting for any text or story that is read aloud [24,58]. **(ages 2-7)**
Informational Features	Tutorials (T)	38. Avoid using in-app tutorials for children; the interface should provide some form of guidance during tasks [17,22]. **(ages 7-11)**
	Instruction Format (IF)	39. Provide an option to have text instructions read aloud [17,24]. **(ages 2-7)** 40. *Add a complementary visual component when using audio instructions such as an animation or highlight [58]. **(ages 2-7)** 41. *Avoid using abstract concepts in children's instructions, e.g., referring to "left" and "right" portions of the screen [17,23]. **(ages 2-7)**
	Advertisements (A)	42. Avoid adding external web links or advertisements to the interface [24,40]. **(ages 2-7)**
Physical		
Gesture and Target Features	Types of Gestures (TG)	43. Avoid gestures such as flick, drag & drop, rotate, pinch and spread to interfaces made for children under age 4 [5,6,66]. **(ages 2-7)** 44. *Avoid adding the double tap gesture for children ages 5 and under, or allow a longer delay between the taps [44,58]. **(ages 2-7)** 45. *Support full-hand gestures for scrolling instead of thumb and index finger gestures, especially for ages 5 and under [26]. **(ages 2-7)** 46. Accept partial gesture completion as children have difficulty with finger-on-screen continuity while dragging [5,58,66]. **(ages 2-11).** 47. *Accept both single and multi-touch input for the same commands, e.g., using two or more fingers during a drag gesture should trigger the same effect as a single-finger drag gesture [66]. **(ages 2-7)** 48. *Accept tap times up to 5 seconds long and target offsets of 10 millimeters for children ages 2 and above [1,66]. **(ages 2-11)** 49. *Use horizontal scrolling instead of vertical scrolling, which is conceptually difficult for children [58]. **(ages 2-7)**
	Gesture Family (GF)	50. *Use consistent gestures throughout the app to avoid confusion [6]. **(ages 2-7)** 51. Use gestures to manipulate objects in children's apps in a manner consistent with the object's use in the real world [6]. **(ages 2-7)**
	Target Size (TS)	52. Increase the active area for interface widgets to allow slightly out-of-bounds touches to count [1,66,71]. **(ages 2-11)** 53. *Provide adequate space between two clickable items to compensate for children's inaccuracy in targeting [6]. **(ages 2-7)**
Socio-Emotional		
Contextual Features	Customization (C)	54. Provide choice and customization features to enhance children's intrinsic motivation and task engagement [22,33,57]. **(ages 2-11)**
	Activity Structure (AS)	55. Consider using an open-ended app structure to support children's engagement and creativity [42]. **(ages 2-11)**
	Social (S)	56. Avoid computer-automated social interactions for children, as they have no effect on their engagement [18]. **(ages 7-11)** 57. *Provide an option for children to credit each other, rather than using automated means of acknowledgment [46]. **(ages 7-11)**

Appendix A: IDC2019 version of the evidence-based Touchscreen Interaction Design Recommendations for Children (TIDRC) framework. Design recommendations noted with asterisks were included in the framework after the empirical app analysis reported in this paper was already completed.

SELECTION AND PARTICIPATION OF CHILDREN

No children participated in this work.

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