Intuitive or Idiomatic? An information-cognitive psychology study of child-tablet computer interaction

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ABSTRACT
Using Luhmann’s communication framework we examine the interaction implications that arise when kindergarten-grade 2 students use mathematics applications on four types of tablet computers. We asked a) what content is communicated between the child and the tablet computer, b) how is content communicated, c) how engaged are children in the tablet-child interaction, and d) what factors influence this engagement. We found that mathematics applications developers across the four platforms have focused on creating applications for the practice of a priori knowledge rather than on creating instructional applications. Also, the overall the emphasis in the applications studied was not to ‘gamify’ mathematics by providing entertainment but to offer a more traditional pedagogy, and that currently there is a low degree of diversity from developers in making use of the range of affordances of tablet computers. This communication studies-psychology interdisciplinary study offers a new conceptual approach to the study of child-tablet interaction.

Author Keywords
Tactile and haptic user interfaces, Computer-Mediated Communication; Handheld Devices and Mobile Computing; Input and Interaction Technologies; Children; E-Learning and Education; Interaction Design; Multidisciplinary Design / Interdisciplinary Design.

INTRODUCTION
In the June 2013 results of a study on worldwide device shipments Gartner Research reported a 67% increase in the sales of tablet computers and an 11% decrease in the sales of personal computers (PC). With estimates of 150 million devices sold to consumers in 2013, and market worth more than US $64 billion in revenue to manufacturers, the popularity of tablet computers is on the rise. Tablet computers - here defined as non-telephony digital mobile-devices with a flat panel screen for both display and primary input of information using fingers or a stylus – are appearing in workplaces, libraries, homes, and increasingly in schools. Across the general population tablet computers are approaching the type of ubiquity applied to predecessors such as laptop computers and mobile phones.

Research examining the implications of using tablet computers in different settings is also emerging including studies on the consequences of use in the fields of medicine (Hess, Santucci, McTigue, Fischer, & Kapoor, 2008; Schefte & Hetland, 2010; Patel, Chapman, Luo, Woodruff, & Arora, 2012), education (Simon, Anderson, Hoyer, & Su, 2004; Eniriguez, 2010), human-computer interaction (Salo, Arihipainen, & Hickey, 2012; Ebner, Stickel, & Kolbitsch, 2010), psychology (Black, Segal, Vitale, & Fadjo, 2012; Hansen, 2013) and library and information studies (Smith & Pietraszewski, 2004; McFall, 2005; Marshall & Bly, 2005) among others. However, interdisciplinary studies that endeavor to reach beyond user-study descriptions and towards novel ways of conceptualizing tablet computer use are less prevalent.

Intrigued by both this deficit in the research literature and by advertiser’s claims regarding the potential of these devices as learning tools for young-users, a research agenda was developed to explore child-tablet interaction using concepts and methods informed by communication studies and cognitive psychology. The goal of the project was to gain insight into the communication and information practices that arise when children use tablet computers.
Specifically, the project examined the types of activities engendered through children’s engagement with tablet computer applications, and the forms of interaction that arise - including examinations of application content, the exchange of information between the child and the tablet, and issues around engagement.

Over the past 40-years the role of technology in education has been a topic of increasing debate among educators and scholars with the question at the heart of the debate, does technology improve learning? Selwyn (2011) takes a historical view of the expectations and concerns with using film, television, radio, and micro-computing to promote gains in student learning and finds that ‘bodies of evidence were produced quickly to prove the effect of these technologies…regardless of the fact that this evidence was inconclusive and equivocal’ (p. 57-58).

Schools are ideal sites for inquiries into the relative merits of using technologies for instruction, but they are also institutions with competing interests for limited resources, and the stakes can be high. Public pressure to stay in-step with technological advancement and prepare students for increasingly technological workplaces must be balanced with evidence that the investments are being used in the best places within the education system. This tension intensifies as the price of technologies drops to within reach of households of countries with higher incomes. This is particularly the case for tablet computers and in 2013 educators are increasingly faced with the reality that the more students in their elementary classes have access to devices and self-described ‘educational applications’ in the home. While some schools, more so in the private systems, attempt to stay in-step or ahead of their constituents, many more school boards are fighting an ideological battle with parents, students, and other stakeholders.

It is within this context that this research project focuses on schools as sites where the need for empirical study of the relationships between learning and technology continue to be centered. Answering the meta-question regarding the efficacy of technologies in promoting learning in schools is beyond the scope of this individual project. Moreover, to determine whether tablet computers are effective learning tools for children one must first understand how children use tablet computers. For similar reasons, we choose not to research comparisons between child-computer interactions versus child-tablet interaction. The goal of this endeavor is to contribute to these debates by focusing inquiry on the forms of interaction between the child and the tablet computer in three distinct ways.

Firstly, what content is communicated between the child and the tablet computer: is the emphasis by developers to promote the exploration of concepts; reinforce classroom instruction though practicing skills; and/or offer more fun and engaging formats for educational material?

Secondly, how is content communicated between the child and the tablet: which features or capabilities of the tablet computers are currently being exploited by developers in applications (e.g., gesture types) and which ones are not; to what extent are children able to successfully execute the input requests of the devices via hand/stylus-based gestures; and can we determine whether or not the information transmitted to the child in the child-tablet interaction is being understood by the child (i.e., when the tablet instructs a child to interact with a specific location on the screen, does the child understand the request)?

Thirdly, how engaged are children in the child-tablet interaction and what factors influence this engagement: comparing different applications and tablet computers to each other; is engagement associated with the types of learning goals in the applications; and what does affect (e.g., facial expressions) and self-report tell us about children’s enjoyment of and motivation to use these devices and applications?

It is important to note that, in a learning context, it is not desirable to separate children’s interactions with a tablet computer from their interaction with a specific application. All educational content is accessed through an application and as such any analysis of child-tablet interaction is, inherently, shaped by the application in use. Thus, the application must be factored into analyses of what content is communicated, how content is communicated, and whether children are engaged.

BACKGROUND

In science, technology, and society (STS) studies scholars consider the co-constitutive relationship between the person using a technology and the technology itself (Bijker, Hughes, & Trevor, 1987; Orlikowski, 1992; Latour, 2005; Suchman, 2007). Instead of viewing the user solely as the recipient of information from the device in a classic transmission-receiver communications paradigm other types of exchange can be understood to be happening. Within STS both the user and the technology are considered to undergo transformations through their engagement with each other (Chatsick, McEwen, & Zbitnew, 2013). Within this conceptual frame the child is not simply a user of the tablet computer since ‘use’ is framed in the co-constitutive interaction sense where it is part of a communications encounter - the child is communicating with the tablet and the tablet with the child.

Luhmann (1992) offers a definition of communication that is useful as we investigate what happens when children engage with tablet computers. While Luhmann applied his theory of communication to large-scale social systems, it offers insight into small-scale interaction as well. For Luhmann communication is an emergent and self-reflexive process involving three forms of encounters with information (or content): a) the selection of information, b) the selection of the utterance of the information, and c) the understanding or misunderstanding of this utterance and its information (Luhmann, 1992). Utterance is relevant to Luhmann’s analysis of human-human communication. In this study of child-tablet computer communication we focus on the child using a touch input to the tablet described as a gesture. Disaggregating the communicative exchange into these forms provides a framework for an analysis of the
content (i.e. what is being communicated), and the process (i.e. how communication is occurring including a means of assessing success). These align closely with the core questions defined in this study.

Regarding our third question on examining the level of engagement that children demonstrate when using tablet computers findings from other studies on user attention-span while using these devices suggests that engagement is average to above average when compared to traditional classroom media (Couse & Chen, 2010; Campigotto, McEwen, & Demmans Epp, 2012; Chatsick et al., 2013). We therefore consider engagement as an influencer on assessing understanding within the child-tablet communicative exchange, and seek to determine specific factors that can be used to measure engagement as a key element to learning in classroom settings.

**METHODS**

**Participants**

To assess how children at the beginning of formal schooling interact with tablet computers, participants were 36 children (n = 12 per grade) from Kindergarten (mean age = 5 Years : 5 months, SD = 8.4 months), Grade 1 (mean age = 7 Years : 0 months, SD = 9.2 months), and Grade 2 (mean age = 7 Years : 5 months, SD = 2.5 months) with an equal number of girls and boys in each grade. Participants were from a single school in a large Canadian city and were predominantly Caucasian (66.7%) with the second largest group being Asian (16.7%) and the remaining participants equally distributed across Spanish, Middle Eastern, First Nations, African, and other. Ethics approval was obtained from the ethics committees of both the University of Toronto and the Toronto Public District School Board. A recruitment letter and parental consent form was sent to the homes of every child in Kindergarten, Grade 1, and Grade 2. For every participant with parental consent, verbal assent was obtained individually on school grounds. All participants who had parental consent and provided verbal assent were included in the study. The study took place in the second half of the school year.

**Procedure**

In individually-administered video-recorded sessions conducted in a small quiet room on school grounds, participants completed two sets of tasks, using educational mathematics applications on a tablet computer and completing cognitive tasks assessing memory and attention. Participants were randomly assigned to use three educational applications on one of four tablet computers (i.e., Apple iPad, Acer Iconia Tab, VTech InnoTab, and LeapFrog LeapPad 2). For each type of tablet computer, the educational applications differed (e.g., the applications used on the iPad were not the same applications used on the InnoTab) because the applications chosen for the study were designed to take advantage of each tablet computer’s unique features. The order in which participants used the three educational applications was balanced across participants. The researcher demonstrated how to begin each educational application and participants used each application for up to 10 minutes or until the participant expressed a desire to move on to the next application.

**Materials**

**Tablet Computers**

The tablet computers in the study represent the range of devices commercially available at the time of data collection while only including tablets that are likely in use by children (i.e., are commercially successful). As shown in Table 1, the four tablet computers differed on six factors, intended user audience, operating system, screen type, screen size, input modalities, and output modalities.

The tablet computers were either designed for an intended user audience of any age (general audience tablet) or specifically designed for use by children (child audience tablet). The operating systems represent the two most commercially successful operating systems on general audience tablets and the two most commercially successful operating systems on child audience tablets. Both screen type and size differed according the intended user audience of the tablet computer. The general audience tablets have larger capacitive screens whereas child audience tablets have smaller resistive screen. Capacitive screens consist of a glass layer coated in conductor material that generates an electrostatic field, which is distorted when touched and this distortion is used to determine the location of the touch. Resistive screens consist of multiple layers separated by a thin space, which is compressed when touched and this point of compression is used to determine the location of the touch. The functional differences between the screens are that capacitive screens allow for multi-touch and a higher frequency of interaction (i.e., more contacts per second) whereas resistive screens only allow for single-touch and have a lower frequency of interaction. The types of input modalities possible on the tablet computers included multi-touch (recognition of two or more points of contact with the screen), single-touch (recognition of one point of contact with the screen), tilt (changing the physical position of the tablet in relevance to its axis), audio (information recorded from the microphone), visual (information recorded from the front facing camera), stylus (a pen-like device used in lieu of touch), and physical buttons. The types of output modalities possible from the tablet computers included audio (sounds emitted from the speakers), visual (images presented on the screen), and haptic (vibration emitted from the device via a small rotating weight contained within the tablet computer).

<table>
<thead>
<tr>
<th>Audience</th>
<th>iPad</th>
<th>Acer Tab</th>
<th>LeapPa</th>
<th>Innotab</th>
</tr>
</thead>
<tbody>
<tr>
<td>OS</td>
<td>iOS 6</td>
<td>Android 3.2.1</td>
<td>LeapFrog</td>
<td>Vtech</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Audience</th>
<th>General</th>
<th>General</th>
<th>Child</th>
<th>Child</th>
</tr>
</thead>
<tbody>
<tr>
<td>OS</td>
<td>iOS 6</td>
<td>Android 3.2.1</td>
<td>LeapFrog</td>
<td>Vtech</td>
</tr>
</tbody>
</table>
### Table 1: Tablet computers

**Educational Mathematics Applications**

The applications chosen for the study contain a broad range of learning mechanics while only including applications that required interaction with the touchscreen as an integral part of the learning mechanic (cf., educational videos). Mathematics applications were chosen because children have less experience with numbers prior to starting formal schooling than they have experience with letters (Lefevre, Skwarchuk, Smith-Chant, Fast, Lamawar, & Bissanz, 2009). Also, use of the mathematics applications does not require participants to be proficient readers. In contrast, applications aimed at improving reading and scientific reasoning both require some language proficiency, which could act as an additional barrier to children’s successful interaction with tablet computers. The criteria used for selecting the applications are as follows:

1. The application is publically available and can be downloaded for free or purchased from the tablet computer’s associated application store.
2. The application does not contain software-programming errors that influence the use of the application.
3. The application contains grade appropriate mathematics material.
4. The application is advertised as an educational mathematics application.
5. The application requires responses from the user to progress the mathematics instruction (i.e., is interactive).
6. The application uses the affordances of its respective tablet computer (e.g., haptic feedback on the Acer Iconia Tab or stylus input on the LeapPad 2).

Having applied these criteria, a search of each tablet computer’s application store resulted in 26 potential applications. After having one of the researchers – an expert in the development of children’s mathematical cognition – test the applications, three educational applications on each of the four tablet computers were chosen for the study (see Table 2). The applications where then classified according to complexity. Simple applications focused on one type of mathematics content and contained one type of learning mechanic. For example, the Vtech Innotab 2S application Number Block Drop focused solely on teaching the concept of time and did so by stating the time and requiring participants to move the hands on a virtual clock to the appropriate position. Complex applications contained multiple types of mathematics content and learning mechanics.

<table>
<thead>
<tr>
<th>Screen Type</th>
<th>iPad</th>
<th>Acer Tab</th>
<th>LeapPad</th>
<th>Innotab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen Size cm</td>
<td>24.6</td>
<td>25.4</td>
<td>12.7</td>
<td>12.7</td>
</tr>
<tr>
<td>Input</td>
<td>Multi-touch, tilt, audio, visual</td>
<td>Multi-touch, tilt, audio, visual</td>
<td>Single-touch, tilt, audio, visual, stylus, button</td>
<td>Single-touch, tilt, audio, visual, stylus</td>
</tr>
<tr>
<td>Output</td>
<td>Audio, visual</td>
<td>Audio, visual, haptic</td>
<td>Audio, visual</td>
<td>Audio, visual</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Games</th>
<th>Math Content</th>
<th>Input</th>
<th>Output</th>
<th>Simple / Complex</th>
</tr>
</thead>
<tbody>
<tr>
<td>iPad:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motion math zoom</td>
<td>Number line estimation</td>
<td>Multi-touch</td>
<td>Audio, visual</td>
<td>Simple</td>
</tr>
<tr>
<td>Number Land HD</td>
<td>Counting, number name</td>
<td>Multi-touch</td>
<td>Audio, visual</td>
<td>Complex</td>
</tr>
<tr>
<td>Park Math HD</td>
<td>Addition, subtraction, equivalence, pattern recognition, counting</td>
<td>Multi-touch</td>
<td>Audio, visual</td>
<td>Complex</td>
</tr>
<tr>
<td>Acer Tab:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Math Maniac</td>
<td>Addition factoring</td>
<td>Multi-touch</td>
<td>Audio, visual, haptic</td>
<td>Simple</td>
</tr>
<tr>
<td>Monkey Math School</td>
<td>Addition, subtraction, pattern recognition, counting, number name</td>
<td>Multi-touch</td>
<td>Audio, visual</td>
<td>Complex</td>
</tr>
<tr>
<td>Lola’s Math Train</td>
<td>Addition, subtraction, pattern recognition, counting</td>
<td>Multi-touch</td>
<td>Audio, visual</td>
<td>Complex</td>
</tr>
<tr>
<td>LeapPad:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dice Ahoy</td>
<td>Probability</td>
<td>Single-touch, stylus</td>
<td>Audio, visual</td>
<td>Simple</td>
</tr>
</tbody>
</table>
Information Transmission

On tablet computers gestures provide a direct interaction with educational content that is not available when using personal computers. This direct interaction with content is what supposedly makes tablet computers more interactive and intuitive than other devices. In each application, a multitude of gestures can be used to interact with content but the specific gestures requested of the user depend on decisions made by an application’s developer. Also, a user may not use every gesture made available to them. Thus, gestures are the quintessential means by which information is transmitted in child-tablet communication. Both the gestures requested by the device and the gestures performed by participants were measured to determine which gestures are used to transmit information.

Understanding

For children to successfully interact with tablet computers, the child must perform the gesture requested from an application (e.g., application requires a tap on the screen and the child taps the screen) and the gesture performed by the child must be recognized by the tablet computer. Thus, correct gesture use is indicative of understanding during child-tablet communication. In contrast, incorrect gesture use is indicative of how communication breaks down and errors in gesture use can be analyzed to determine whether understanding falters at either the child or the tablet computer. The proportion of correct and incorrect gesture use was measured to determine how successfully participants communicated with the tablet computers. Interactions in which the requested gesture was performed and correctly recognized by the tablet computer (i.e., agreement) indicated successful communication. Interactions in which the requested gesture was not performed (i.e., child’s error) indicated a communication failure at the child’s level. Interactions in which the requested gesture was performed but was not correctly recognized by the tablet computer (i.e., tablet’s error) indicated a communication failure at the device level.

Engagement Observations

Participants’ engagement with each application was measured using a combination of behavioural observations and self-report measures. The engagement measures used in the study are modeled off the measures used by Fisher, Dobbs-Oates, Doctoraff, and Arnold (2012) who assessed children’s engagement in paper and pencil mathematics tasks. The measures index engagement with the hypotheses that engaging applications are used for longer periods of time, are used in a goal-directed manner, and are more enjoyable to use.

Time Used

Participants were instructed that they could use each application for up to 10 minutes and that they could stop at any time and switch to the next application. Using the video recording, the amount of time used was measured from the point the participant started using an application until the participant stated they wanted to stop using the application or until the cutoff had elapsed.

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**Table 2: Educational mathematics applications**

<table>
<thead>
<tr>
<th>Games</th>
<th>Math Content</th>
<th>Input</th>
<th>Output</th>
<th>Simple / Complex</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-Rex Rush</td>
<td>Counting, magnitude, number name</td>
<td>Single-touch, tilt, stylus, Buttons</td>
<td>Audio, visual</td>
<td>Complex</td>
</tr>
<tr>
<td>Kat's Matherrific Magic Show</td>
<td>Addition, subtraction, counting</td>
<td>Single-touch, stylus, Buttons</td>
<td>Audio, visual</td>
<td>Complex</td>
</tr>
<tr>
<td>Innotab:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Numbe r Block Drop</td>
<td>Ordinality</td>
<td>Single-touch, stylus</td>
<td>Audio, visual</td>
<td>Simple</td>
</tr>
<tr>
<td>Cuckoo Clock</td>
<td>Time</td>
<td>Single-touch, stylus</td>
<td>Audio, visual</td>
<td>Simple</td>
</tr>
<tr>
<td>Mad Dash Math</td>
<td>Magnitude, counting, pattern recognition</td>
<td>Single-touch, stylus, audio</td>
<td>Audio, visual</td>
<td>Complex</td>
</tr>
</tbody>
</table>

**Measures**

**Child-tablet Communication**

Child-tablet communication was video recorded during data collection and coded after data collection was complete. The coding focused on four areas, the information selected for communication (i.e., application content), the transmission of information (i.e., gestures), the degree to which the transmission was understood (i.e., gesture agreement), and child engagement with the tablet computer (i.e. time spent, goal-direction, and enjoyment).

**Information Selected for Communication**

Three indices of application content were measured, instruction versus practice, mathematics content versus entertainment content, and motivation. First, the proportion of time spent on instruction on how to use an application, time spent on mathematics instruction, time spent openly exploring content, and time spent practicing mathematics knowledge where measured to determine how educational mathematics applications attempt to improve mathematics understanding. Second, the proportion of time spent on mathematics content versus time spent on content unrelated to mathematics (i.e., entertainment) was measured to determine how much time using the applications is spent on task relevant content. Third, the frequency with which positive reinforcement, negative reinforcement, non-contingent reinforcement, punishment, and token economies occurred during application use was measured to determine how participants are motivated to progress through an application.
**Goal-directed Use**
During data collection, goal-directed use was measured by the researcher assessing the structure and sophistication of the participant’s application use, as well as sustained attention to the task. Participants who promptly completed the learning goals and generally seemed organized received high ratings for goal-directed play. Ratings ranged from 1 (random approach to application use) to 7 (consistent and purposeful approach to application use).

**Enjoyment**
Enjoyment focused on participants’ level of engagement, eagerness, and positive affect while using the learning applications. Enjoyment was assessed in two ways, researcher observation and participant self-report. For the researcher observation, the researcher considered the amount of fun the participant seemed to have and their enthusiasm towards using the application. Participants who made positive verbal statements (e.g., “This is fun”) and facial expressions (i.e., smiles) received high ratings in enjoyment (cf. negative statements and frowns or overt disinterest in using the application). Researcher observations ratings ranged from 1 (did not enjoy at all) to 7 (complete enjoyment). For participants’ self-reports of enjoyment, immediately following the use of an application, participants were asked how much they liked the application. Participants were given the binary choice of either a little (the researcher held their hands close together) or a lot (the researcher held their hands apart at arm-length). After using all three applications, participants were asked how much they enjoyed using the tablet computer (not the applications), a little or a lot, and asked which application of the three they enjoyed using the most.

**RESULTS**

**Child-tablet communication**
Child-tablet communication was coded by analyzing the video data using the behavioural coding software CAPT-IV. To account for the varying amount of time with which participants used each application (i.e., participants could stop using an application at any time), only the first and last minute of application use was coded. The first minute of use was chosen so the data captured a learning phase of child-tablet communication in which participants were unfamiliar with both the content of an application and how to use the application. In contrast, the last minute of use captured more established child-tablet communication.

To maximize reliability of the video coding, two research assistants independently coded the same 10% of the videos (i.e., four participants) and differences between research assistants’ measurements were compared. For example, the measurement of time spent on educational content versus time spent on entertainment content was compared between the two researchers. On 90% of all comparisons, the researchers differed on average by 5 seconds. On the remaining 10% of comparisons, the researcher’s differed on average by 57 seconds. The instances of major disagreement were resolved through discussion amongst the researchers. After establishing the coding scheme, the research assistants each coded half of the remaining videos and further ambiguities were resolved by discussion.

**Information Selected for Communication**
The proportion of time spent on instruction on how to use an application, time spent on mathematics instruction, time spent openly exploring mathematics, and time spent practicing mathematics knowledge was analyzed using a repeated measures analysis of variance (ANOVA) to determine how educational mathematics applications attempt to improve mathematics understanding (see Figure 1). Significantly more time was spent on practicing mathematics knowledge than instruction or on openly exploring mathematics, $F(3, 105) = 518.99, \text{MSE} = 137.34, p < .001, \eta^2 = .94$. Differences among learning mechanics where evaluated using confidence intervals [16].

Error bars represent 95% confidence intervals.

**Figure 1: Proportion of application use by learning mechanic**

The proportion of time spent on mathematics content versus time spent on content unrelated to mathematics (i.e., education vs. entertainment) was analyzed using a paired sample t-test. More time was spent on mathematics content ($M = 77.6\%, \text{S.E.} = 5.1$) than on entertainment content ($M = 21.8\%, \text{S.E.} = 5.1$), $t(35) = 5.45, p < .001$.

The frequency with which positive reinforcement, negative reinforcement, non-contingent reinforcement, punishment, and token economies occurred during application use was analyzed using a repeated measures ANOVA to determine how participants are motivated to progress through an application (see Figure 2). The order of most frequent to least frequent motivator use is as follows: positive reinforcement, non-contingent reinforcement, punishment, token economies, and negative reinforcement, with significant differences among positive reinforcement and all other motivators and between non-contingent reinforcement and token economies, $F(3, 105) = 72.998, \text{MSE} = 495.580, p < .001, \eta^2 = .68$. Differences among motivators where evaluated using confidence intervals [16].
Error bars represent 95% confidence intervals.

**Figure 1: Proportion of application use by motivation mechanic**

**Information Transmission**
The gestures requested by the device and the gestures performed by participants were coded and a total of seven gesture types were identified (see table 3). The majority of gestures were coded by watching the video and counting the number of times each gesture was performed. However, the use of the physical buttons on the LeapFrog was not amenable to this coding scheme because the buttons were pressed for varying periods of time (e.g., tapping the screen for a brief moment). To compare gesture types, the total amount of time spent pressing physical buttons was measured and a time value of .5 seconds was assigned to the other observed gestures (e.g., 1 tap = tapping for .5 seconds, 2 taps = tapping for 1 second). Two 4 (tablet computer: iPad, Iconia Tab, LeapPad, and Innotab) x 7 (gesture type: tap, swipe, drag, pinch, tilt, buttons, and blow) ANOVAs were performed on the amount of time gestures were requested by the device and the amount of time participants spent performing gestures (see Figure 3). There was a significant Tablet Computer X Gesture Type interaction for both the requested and performed gestures, $F(18, 192) = 38.71$, $MSE = 53.183$, $p < .001$, $\eta^2_p = .78$, $F(18, 192) = 37.71$, $MSE = 55.09$, $p < .001$, $\eta^2_p = .78$, respectively. Comparing the two figures suggests that the Tablet Computer X Gesture Type interaction was nearly identical for both the gestures requested and the gestures performed. Using the confidence intervals, the data suggest that tap and then drag were the most frequently used gestures on all devices whereas the button, blow, pinch, swipe, and tilt gestures were more device specific.

**Figure 3: Gestures requested (top) and performed (bottom)**

<table>
<thead>
<tr>
<th>Gesture</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tap</td>
<td>Touching the screen at a singular location, for a brief period of time, using a finger or stylus.</td>
</tr>
<tr>
<td>Swipe</td>
<td>Touching the screen using a finger or stylus at an initial location, then moving in a straight line to an unspecified secondary location, while remaining in contact with the screen.</td>
</tr>
<tr>
<td>Drag</td>
<td>Touching the screen using a finger or stylus at an initial location, then moving in a straight line or in a complex pattern to a specific secondary location, while keeping in contact with the screen.</td>
</tr>
<tr>
<td>Pinch</td>
<td>Placing two fingers on the screen and bringing them either closer together or farther</td>
</tr>
<tr>
<td>Tilt</td>
<td>Changing the position of the device in relevance to its Horizontal axis.</td>
</tr>
<tr>
<td>Button</td>
<td>Using the directional pad on the LeapPad.</td>
</tr>
<tr>
<td>Blow</td>
<td>Forcing air into the microphone (i.e.,</td>
</tr>
</tbody>
</table>
the iPad, and 16.44 for the LeapPad. For participant ratings, 17.28 for the InnoTab, 17.25 for the Iconia Tab, 17.00 for significance ($H(3) = .042$, $p = .998$) with a mean rank of the differences among the tablet computers did not reach participant self-reports of enjoyment. For researcher ratings, ratings of participant enjoyment and on the summed ANOVAs were performed on the summed researcher Enjoyment. However, the differences among the tablet computers did not reach significance ($H(3) = 5.552$, $p = .136$) with a mean rank of 20.28 for the InnoTab, 19.50 for the LeapPad, 18.67 for the Iconia Tab, and 15.56 for the iPad.

**DISCUSSION**

Regarding the first research question, what content is communicated between the child and the tablet computer, we found that developers across the four platforms have focused more on creating applications for the practice of mathematical knowledge that the children were likely to have been taught prior to using the devices, versus offering instruction, or more open-ended opportunities for exploring mathematics concepts. In addition, overall the emphasis in the applications studied was not to ‘gamify’ mathematics by providing entertainment, but to offer a more traditional pedagogy with positive reinforcement as the principle motivating technique.

With respect to the second question, how is content communicated between the child and the tablet, we found a low degree of diversity from developers in making use of the range of affordances of tablet computers. Tap and drag were the main gesture requests and responses evidenced in the communicative exchanges between the children and the tablet computers. We also found that the gesture agreement between the child and the tablet was high, indicating that there was a strong degree of understanding within the interactions. While this concurs with anecdotal evidence that implies a native affinity that children have for tablet devices, it also suggests that the basis of the ease with which children interact with tablet computers is in part due to the narrow range of gestures required in the interaction.

In the third question we were interested in how engaged are children in the child-tablet interaction and what factors influence this engagement. We found that children spent the most time in active engagement with the non-child specific devices, i.e. the iPad and the Iconia Tab. This may suggest a relationship between attention-span and capacitive versus resistive screen formats, but further research is required to determine why this result demonstrates significance. We also note that larger sample sizes are required from further studies to consider the role of goal direction as a factor in motivation across different tablet computer platforms.

We also experimented theoretically and methodologically by using Luhmann’s conceptual framework to guide the philosophy of the study, while employing techniques and principles from psychology to design the study and aid in data analysis. The results from the information selected for communication and information transmission sections offered evidence of the form and nature of the content that was provided by the tablet computers (via the applications) to the child within the communicative exchange. We were also able to identify the form and content of what the child provided to the tablet computer in the interaction. In the understanding sections we could examine closely whether the communication between the child and the tablet computer was successful – where success was quantitatively measured by analyzing gesture agreement.

**Table 3: Gestures observed during child-tablet interaction**

**Understanding**

A 4 (tablet computer: iPad, Iconia Tab, LeapPad, and Innotab) x 3 (gesture alignment: agreement, child’s error, tablet’s error) ANOVA was performed on the proportion of correct and incorrect gesture use to determine the degree of successful communication (see Figure 4). The main effect of Gesture Alignment was significant but the Gesture Alignment x Tablet Computer Interaction was not significant, $F(2, 64) = 834.789$, $MSE = 109.272$, $p < .001$, $η^2 = .96$, $F < 1.00$, respectively. Overall, there was more gesture agreement than either child or tablet error.

![Figure 4: Gesture alignment by tablet computer](image)

**Engagement Observations**

**Time Used**

A 4-level (tablet computer) one-way ANOVA was performed on the amount of time used (in seconds). Application use was longest on the iPad ($M = 1526$, $S.E. = 102$), followed by the Iconia Tab ($M = 1331$ seconds, $S.E. = 96$), LeapPad ($M = 1207$, $S.E. = 96$), and InnoTab ($M = 943$, $S.E. = 96$), $F(3, 31) = 6.07$, $MSE = 83950.208$, $p = .002$, $η^2 = .37$, HSD = 393. The iPad was used longer than the LeapPad and Innotab, which did not differ from each other. Both the the Iconia tab and LeapPad did not differ in use but were both used more than the Innotab.

**Goal-directed Use**

A 4-level (Tablet Computer) Kruskall Wallis one-way ANOVA was performed on the summed ratings of goal-directed play. The differences among the tablet computers did not reach significance ($H(3) = 5.552$, $p = .136$) with a mean rank of 20.28 for the InnoTab, 19.69 for the LeapPad, 14.14 for the Iconia Tab, and 11.13 for the iPad. However, the lack of difference could be due to the small sample size.

**Enjoyment**

Two 4-level (Tablet Computer) Kruskall Wallis one-way ANOVAs were performed on the summed researcher ratings of participant enjoyment and on the summed participant self-reports of enjoyment. For researcher ratings, the differences among the tablet computers did not reach significance ($H(3) = .042$, $p = .998$) with a mean rank of 17.28 for the InnoTab, 17.25 for the Iconia Tab, 17.00 for the iPad, and 16.44 for the LeapPad. For participant ratings,
and qualitatively assessed through video observations. We found that Luhmann’s communication framework was useful. Having established this framework for interpreting child-tablet interaction, future work can now go beyond the fundamental questions asked herein. For example, how do device affordances affect communication success in applications with varying learning goals (e.g., reading, mathematics, scientific reasoning)?

CONCLUSION

Tablet computers represent another example of a new medium that is entering the everyday lives of children with the promise of providing a learning platform. Using Luhmann’s communication framework for observing interactions, we designed an interdisciplinary study bringing information studies conceptual framing and cognitive psychology techniques to investigate what occurs when children use tablet computers and mathematical applications. As far as we know this is the first study to do so successfully.

These results show preliminary evidence that child-tablet communication is, on the whole, successful but this success comes at the cost of richer, multi-modal interactions. Tablet computer application developers are being cautious in offering a variety of options for children to interact with the devices, and we suggest that there is scope for a broadening of the communicative interaction modes. Yet we are in the early phase of the development of child-targeted applications on tablet computers and anticipate greater diversity in the future. The question will be whether diversity is reached by developers strategically creating applications armed with knowledge of how children interact with tablet computers or whether a trial and error approach will be taken, with some developers stumbling upon successful modes of child-tablet communication.

While a single study cannot provide a complete answer to the decades-long question does technology improve learning we believe that these results offer an important contribution to the debate by providing deeper insight into nature of child-tablet computer interactions, and also offer new and interdisciplinary conceptual lenses from which we can investigate the question.

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