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Engaging or Distracting: Children's Tablet Computer Use in Education

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ABSTRACT

Communications studies and psychology offer analytical and methodological tools that when combined have the potential to bring novel perspectives on human interaction with technologies. In this study of children using simple and complex mathematics applications on tablet computers, cognitive load theory is used to answer the question: how successful are tablet computer educational applications at directing children's attention towards intrinsic and germane content? An eye tracker collected gaze data and cognitive tasks were performed to assess memory and attention. The results show that simple applications are able to direct a child's attention to intrinsic and germane content, regardless of the child's cognitive ability. Children assessed as high executive functioning found the germane content of the complex applications helpful whereas children assessed as lower executive functioning did not take advantage of the germane content. Claims that the cognitive structure of the individual is intimately linked to the forms or systems of communication used were partially supported. The research showed that tablet computers and their applications offer a learning experience that appears to be inherently highly interactive—thereby introducing challenges to the cognitive load of children as users.

Keywords

Cognitive load, Eye tracking, Tablet computers, Executive functioning, Child-tablet interaction

Introduction

Tablet computers are being used for educational purposes but there is little examination of how users interactions with these technological objects affect the learning process. Several disciplines have an interest in the relationship between sensory explorations of objects and processes of knowledge creation. Cultural theorists focus on the contribution of societal norms and expectations to epistemic encounters that historically range from 15th century analyses of witchcraft (Classen, 2005), to mid-18th century chemists (Roberts, 2005), and to modern issues involving sensory dis-integration in mental illness (Desjarlais, 2005). Philosophers have a long-standing curiosity in, for example, the roles that sensory perception and belief play in human understanding - spanning physical and metaphysical engagements with everyday objects (Descartes, 1984; Armstrong, 1973; Rorty, 1979; Goldman, 1986). Information and communication scholars consider issues of preservation, material culture and making, memory, and information processing and grapple with the challenges that arise from people's direct engagement with content (Howarth, 2005; Fisher, Erdelez & McKechnie, 2005). Most notably, cognitive psychologists have established a canon of knowledge contesting and also linking physical experiences, with mental processes and representations. The body of work on cognitive load in particular offers researchers a conceptual framework within which to examine interactions (e.g., Lee, Plass, & Homer, 2006; Paas, Renkl, & Sweller, 2004; van Gog, Kester, Nievelstein, Giesbers, & Paas, 2009). It is the latter two disciplinary approaches that influence the conceptual foundation for this study of how users interact with and make sense of tablet computers. Communications studies and psychology offer analytical and methodological tools, and when combined they have the potential to bring novel perspectives on human interaction with technologies.

Touching, seeing, and cognitive load

Relatively new media devices like smartphones, interactive whiteboards, and tablet computers (e.g., iPads, Innotabs, Android tablets, LeapPads) engage users through touch-interfaces where tactile, visual, and to an optional degree, auditory senses are highly involved in the device-user exchange. In communications studies, scholars like Rowland (2012) theorize that historically technologies have had differential impacts in the defining characteristics of our capacities. Regarding literacy, Botha (1992) posits that "the very cognitive structure of the individual and the formal patterns of human social relations are intimately linked to the forms or systems of communication [used] sic…" (p. 273). For tablet computers, visual information drives the interaction and likely affects cognitive structure.

In comparison to forms of digital communication available to the general public before sales of tablet computers in 2010, the degree of user-medium interactivity has increased. Yet, questions remain about the extent to which these forms of interaction affect the user, especially questions regarding the nature of the link between communication technologies and potential changes to a user's "cognitive structure." Given the broad, rapid adoption of tablet computers in education, it is increasingly important to question how this technology interacts with and affects cognitive structure. This leads to the primary motivation of the present study: to explore the relationship between a user's engagement with tablet computers and that user's cognitive load.

Cognitive load results from the short-term information processing activities of the mind when various information elements are being held and manipulated simultaneously (Sweller, 1994). The short-term system for storing and manipulating information is called working memory (Baddeley, 2003) and it is a finite resource that can be overwhelmed (i.e., cognitive overload). To partially overcome the limitations of working memory, information acquired during learning is organized into schemas. A schema is defined as "a cognitive construct that organizes the elements of information according to the manner with which they will be dealt" (Sweller, 1994, p. 296). Cognitive load theory groups schemas created during learning into three types: (a) intrinsic, load that is the inherent to level of difficulty associated with specific content; (b) extraneous, load associated with how information is presented to users; and (c) germane, load generated by the processing, creation, and automation of schemas (Sweller, Van Merriënboer & Paas, 1998). These three types of cognitive load are present to varying levels during all learning tasks and the goal of instruction, within this paradigm, is to best align the learning content to human cognitive architecture. That is, instructional content should be optimized such that cognitive effort is directed towards intrinsic and germane content and away from extraneous content (Paas et al., 2004).

Tablet computers are thought to be effective learning tools because they contain multimedia content that engages users, but it is not known whether users are engaged with the right content. Cognitive load theory has been used to frame how learning generally occurs in multimedia rich environments. Multimedia can be defined narrowly as learning from both words and pictures simultaneously (Mayer, 2001) or more broadly as learning from multiple sensory channels simultaneously (e.g., pictures and audio). When learning using tablet computers, cognitive overload can arise from presenting intrinsic content across both words and pictures simultaneously—such that it cannot be effectively integrated into working memory due to the splitting of attention—or presenting incidental extraneous content in one format that diverts attention away from the intrinsic content presented in another format (Mayer & Moreno, 2003). This overload can be addressed by synchronizing intrinsic content across formats—presenting redundant, reinforcing content that limits the effort required for integration; limiting the competition between extraneous and intrinsic content by reducing their simultaneous presentation (Kaminski & Sloutsky, 2013); or by individualizing content so that it speaks to the cognitive strengths of the user (i.e., visual content for users with larger visual short-term memory; Mayer & Moreno, 2003). Individualizing content is particularly interesting because it highlights how individual differences in users' cognitive ability influence cognitive overload. It is not known whether the visual content on tablet computers adequately address cognitive overload.

In user-tablet computer interactions the app directs the user's attention and cognitive activity towards information visually presented on the screen. In investigating tablet computers and the relationship between touching these devices and cognitive load, the contribution of visual information must be considered as it communicates the gestural responses required from the user. This sensory interplay between touching and seeing was also noted by communications theorist McLuhan (2005) when he draws from sculptor Adolf Hildebrand's insistence in 1893 that "true vision must be much imbued with tangibility." (p. 43). In addition, keeping with evidence from neuroscience on the interconnectedness of sensory areas of the brain (Sacks, 2005) it is useful to focus attention on what the user looks at when using tablet computers to learn.

Tablet computers and education

There is a longstanding and often controversial tradition of co-opting the use of electronic media technologies for education. From the use of educational radio programs in the classroom in the 1920's and 1930's (Atkinson, 1942), to the use of television in elementary school curricula (Cuban, 1986), and the use of computers within formalized learning settings (Coley, Cradler & Engel, 1997), technologies have continually held the promise of improving the learning process. Tablet computers follow in this trajectory and are increasingly a part of the classroom experience from pre-school to tertiary education (Henderson & Yeow, 2012; Mang & Wardley, 2012, Chatsick, McEwen & Zbitnew, 2013).

When the purchase price of a technology eventually falls within the reach of the middle-class, these devices are increasingly used to educate outside of classrooms and within homes – often in the form of children using tablet computers under the purview of parents and caregivers. From the time of their first introduction to the market, the relatively low price of tablet computers contributed to their rapid adoption worldwide, with the research firm Gartner estimating 195 million devices sold in 2013 alone (Lunden, 2014). This has led the use of tablets for educational purposes in homes as well as in schools and device brands actively target parents for the sale of devices.

As was the case of the initial adoption of past technologies for educational purposes in schools and in homes, there is little formalized direction regarding the use of these devices – questions such as which tablet computers are most appropriate for which setting; which applications (software programs running on the tablet computers) best lead to preferred outcomes; or how to teach users to operate tablet computers - remain unanswered. Trial-and-error predominates and users base choices regarding devices and applications from their personal interests in a particular topic, cost (where free applications are especially attractive), word of mouth, or as a result of marketing efforts on- and off-line. Since users and particularly young users are often left to engage with the devices in a non-directed manner, we replicate this practice of non-directed user engagement with tablets in our study design as we investigate the effect of using these devices on cognition. Thus, our study involved not instructing participants on how to interact with the applications during tablet computer use.

Allowing users to engage with tablet computers and applications in a non-structured manner focuses the inquiry on how the app on the tablet computer directs the user. Luhmann (1992) in his seminal essay on communication proposes that we can assess understanding in communicative encounters by analyzing what information was requested and what information was expected in return. In tablet computer-user communications the app, in this case classified as educational, presents visual information directing the user to perform a touch or gestural response on the surface of the device. Typically, the user must determine which elements presented on the screen represent salient information (i.e., what are they being directed to do), and then the user must choose and execute gestural actions to satisfy the informational request. Sweller (1994) also considered the impact that learning interactivity has on cognitive load, where complex learning activities can either over or under load working memory and affect the development of schemas. Therefore, in app-directed communicative exchanges there are two contributing factors of interest: (i) app complexity, and (ii) the user's cognitive ability.

Research questions

Considering the wide spread adoption of tablet computers in education and the dearth of research in this area, we pose the following research questions:

RQ1. How successful are educational applications on tablet computer at directing user's attention towards intrinsic and germane content? This is achieved by comparing simple and complex applications to determine which of these two approaches to app design is more successful. Successful engagement is operationally defined as user's (in this case children) (i) attending more to intrinsic and germane content than extraneous content and (ii) self-reporting that they enjoy the content.

RQ2. To what extent does a user's cognitive ability affect engagement with educational applications? Assess whether a child's cognitive ability affects how they successfully engage with educational content on tablet computers. Investigate whether or not children with more available short-term memory, working memory, and better attentional control are better able to direct their cognition towards intrinsic and germane content and away from extraneous content?

RQ3. Do application complexity and children's cognitive ability interact?

Method

Participants

Participants were 30, English-speaking children (13 male) in Grade 2 with a mean age of 7 years and 3 months (range: 6 years, 8 months to 7 years, 9 months). Participants were from a single school in a large Canadian city. Ethics approval was obtained from the ethics committees of both the University of Toronto and the Toronto District School Board. A recruitment letter and parental consent form was sent to the homes of every child in Grade 2. All participants with parental consent participated in the study and provided verbal assent immediately prior to their participation. Only data from neurologically typical children are included in the reported results—neurological state was determined by asking teachers if the participant was formally assessed as neurologically atypical (e.g., assessed as having/being: a mild intellectual disability, Downs Syndrome, on the autism spectrum). The study took place in the first half of the 2013-2014 academic year.

Procedure

In individually-administered sessions conducted in a quiet room on school grounds, participants completed two sets of tasks. For the first set of tasks, participants used educational mathematics applications on two tablet computers (i.e., iPad & LeapFrog LeapPad 2) while gaze data was recorded with a desktop mounted 60Hz FaceLab 5 eye tracker (see Figure 1). Using the eye tracker entailed a four-point calibration procedure in which participants look at the four corners of the tablet computer screen while the eye tracker triangulates their gaze position for each location. The calibration procedure was conducted twice for each participant, once per tablet computer. After a successful calibration, the researcher demonstrated how to begin each educational application and participants used each application for a total of two-minutes. This duration was chosen so that the data would capture children's initial interaction with an educational application (i.e., a learning phase). Following the use of each application, participants' engagement with the application was assessed using self-report. Half of all participants used the iPad first and half used the LeapPad first. The order of the applications on each tablet computer was also cross-balanced. For the second set of tasks, participants completed four cognitive measures assessing short-term memory, working memory, and attention. All participants completed the cognitive tasks in the same order.

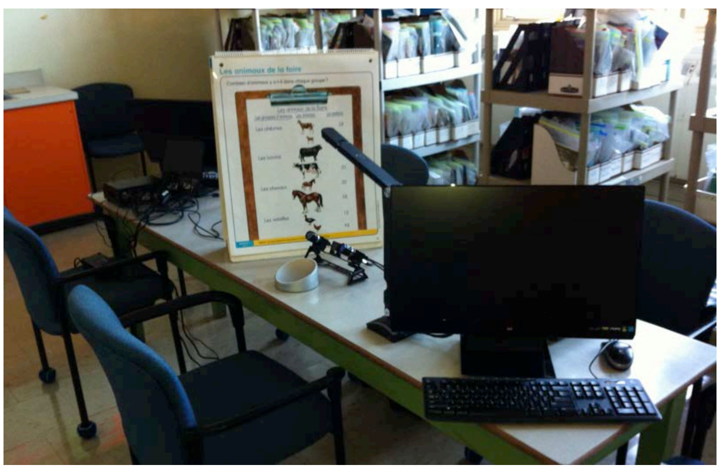


Figure 1. Testing room with desktop mount eye tracker

Materials

Tablet computers

The two tablet computers in the study represent a sample from the range of devices commercially available at the time of data collection, and also represent tablet computers that are most likely to engage children. In a previous study assessing children’s interaction with tablet computers (i.e., iPad, LeapPad, Acer Iconia Tab, and VTech InnoTab), it was found that tablet computers designed for a general user audience (iPad & Iconia Tab) appear to be more engaging—are played longer, are used in a more goal-directed manner, and are judged as more enjoyable by both researcher observation and user’s self-reports—than tablets specifically designed for use by children (e.g., LeapPad & InnoTab; McEwen & Dubé, 2015), with the iPad and LeapPad garnering the most engagement in their respective categories.

Educational mathematics applications

One goal of the present study is to determine how successful tablet computers are at directing children’s attention towards intrinsic and germane educational content (cf., extraneous content). In this context, child-tablet interaction is mediated through application use. To assess the role applications have in user engagement, two applications on each of the tablet computers were chosen. The applications in the present study were chosen because (a) in a previous study they were found to be more engaging than applications on competing tablet computers (McEwen & Dubé, 2015) and (b) the applications represented diametrically opposed approaches on how to engage users, simplicity vs. complexity. Simple applications focused on one type of mathematics content, contained one type of learning mechanic, and had relatively plain visuals. Complex applications contained multiple types of mathematics content and learning mechanics and used relatively dynamic visuals (see Table 1).

Measures

Participants’ engagement with each application was measured using eye tracking metrics and a self-report measure. The selection of eye tracking metrics reported in the present study was chosen from a broader range of eye tracking data automatically produced by the software Eyeworks. The self-report measure was modeled off of work by Fisher, Dobbs-Oates, Doctoraff, and Arnold (2012), who assessed children’s engagement in paper and pencil mathematics tasks. This measure indexes engagement with the hypotheses that engaging applications are more enjoyable to use.

Eye tracking measures of engagement

Fixation count. Fixations are moments of relative stability in the eye during which encoding occurs (Poole & Ball, 2006). Fixation count is the total number of fixations in a given area of interest (AOI), with more fixations indicating that the areas is more noticeable or important to the user than other areas (Poole, Ball, & Phillips, 2005).

Fixation duration. Fixation duration is the average length of an individual fixation. Longer fixation durations within an AOI indicate difficulty in extracting information from that area (Just & Carpener, 1976).

Gaze. Gaze is the sum of all fixation durations within an area (Poole & Ball, 2006). Gaze can be used to visually compare how attention is divided between multiple AOIs with a stronger gaze indicating that more attention is directed to one area over another (Mello-Thoms, Nodine, & Kundel, 2002).

Self-report of engagement

Immediately following the use of each application, participants were asked how much they liked the application by presenting them with a line bounded by two choices.

I did not like it———————————I liked it a lot

To indicate their attitude towards the application, participants were instructed to place a mark on the line between the two choices. The distance from the left-most position on the line to the mark was used as an index of participants’ self-report of engagement.

Table 1. Educational mathematics applications

Application	Math content	Complexity	Example screen image
Motion Math Zoom	Number line estimation	Simple	
Number Land HD	Counting, number identification and production	Complex	
Dice Ahoy	Probability	Simple	
T-Rex Rush	Counting, magnitude comparison, number and symbol identification	Complex	

Note. EXT = Extraneous, INT = Intrinsic, GER = Germane.

Cognitive tasks

Two tasks were used to assess the capacity of participants' short-term memory, one task was used to assess working memory, and one task was used to assess attention.

Memory tasks. The forward digit span, spatial span, and reverse digit span tasks were used as measures of verbal shot-term memory, visual short-term memory, and working memory, respectively (Alloway & Alloway, 2010; Gathercole & Pickering, 2000; Wiseheart, Altmann, Park, & Lomardino, 2009). For the forward and reverse digit span, the researcher read aloud a series of single-digit numbers at 1 second intervals. For the forward digit span task, participants were instructed to repeat the digits in the same order in which they were presented, which requires the numbers to be stored in verbal short-term memory. In the reverse digit span task, participants were instructed to repeat the digits in the reverse order, which requires the number to be manipulated in working memory. For the spatial span task, twelve shaded and identical circles were presented on a piece of paper. The researcher pointed to the circles sequentially and the participant was to touch the same circles in the same order, which requires the series to be stored in visual short-term memory. The series of numbers and circles were initially three items long and increased by one item after every correct repetition by the participant (Werheid et al., 2002). No feedback was given throughout the tasks. Responses were recorded as either right or wrong. The task ended after the participant incorrectly repeated two series with the same number of items. The longest correctly repeated series was recorded as a participant's score.

Attention task. Manly et al.'s (2001) Opposite World task from the Test of Everyday Attention for Children (TEA-CH) was used as a measure of controlled attention. Participants were presented with a stimulus sheet containing a mixed array of the digits 1 and 2 (see Figure 2). There were two conditions, same world and opposite world. In the same world condition, participants were asked to read the digits aloud as quickly as possible from start to finish. In the opposite world condition, participants were asked to say the opposite for each digit (saying 1 for 2 and 2 for 1) as quickly as possible, which requires attention to be directed at the goal at hand (saying the opposite) by inhibiting the prepotent response (e.g., saying 1 for 1). In the task, participants only progressed to the next digit following a correct response, thus errors were incurred as a time penalty. Following a practice in each condition, four test pages were run in the same world condition and then four pages were run in the opposite world condition. The amount of time to complete each page was recorded using a stopwatch. The difference in total completion time between the opposite world and the same world task was taken as the dependent variable, with smaller differences indicating better controlled attention.

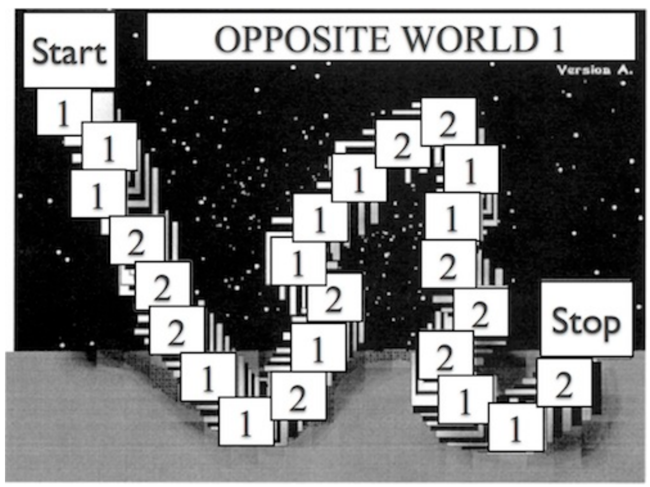


Figure 2. Example trial from controlled attention task

Results

RQ1. How successful are educational applications on tablet computer at directing user's attention towards intrinsic and germane content?

To determine how successfully applications direct children's attention towards intrinsic and germane content and away from extraneous content, two 2 (complexity: simple, complex) x 3 (content: intrinsic, germane, extraneous) ANOVAs were performed on the fixation count and fixation duration data. Intrinsic content included visuals that were required to complete the learning task (e.g., numbers, symbols, counting manipulatives). Germane content included visuals that scaffold the learning task but was not necessary to complete the task (e.g., progress markers, avatars/characters that offered aid on request, animations that reinforced the learning task). Extraneous content included visuals that did not aid the learning task (e.g., interactive and static background visuals, navigational buttons). Examples of the content areas can be found in Table 1. Five participants' eye tracking data are excluded in the analyses due to poor calibration.

For fixation count, there was a main effect of complexity with more fixations for the simple applications than the complex applications, $F(1, 50) = 13.699$, $MSE = 1071.233$, $p = .001$. There was also a main effect of content type with more fixations in the intrinsic and germane content than in the extraneous content, $F(2, 50) = 19.289$, $MSE = 1071.233$, $p < .001$. These results suggest that the simple applications are more noticeable/important than the complex applications and that the intrinsic and germane content are more noticeable/more important to the children than the extraneous content (see Figure 3).

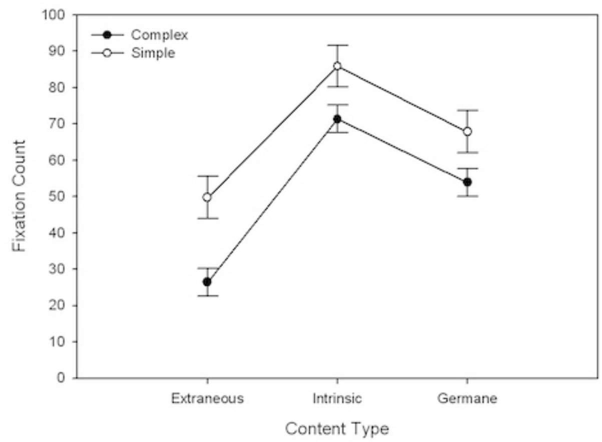


Figure 3. Fixation count by complexity and content (error bars = *se*)

For fixation duration, there was a non-significant trend for the average fixation to be longer for the simple applications than for the complex applications, $F(1, 50) = 2.973$, $MSE = .1$, $p = .09$. No other main effects or interactions are significant. However, the graphed data do provide some insight into the trend (see Figure 4), with longer fixations in the extraneous and germane content for the complex applications.

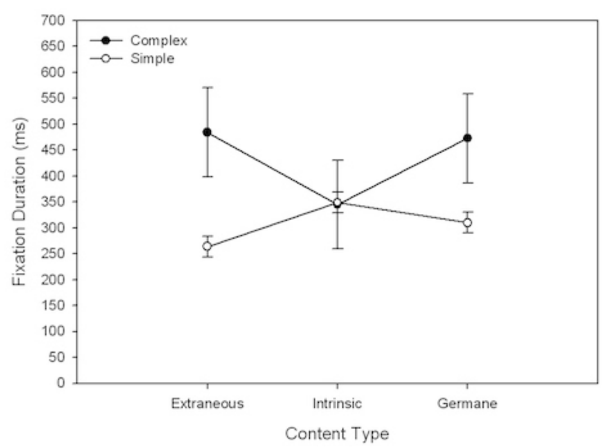


Figure 4. Fixation duration by complexity and content (error bars = *se*)

RQ2. To what extent does a user's cognitive ability affect engagement with educational applications?

To determine whether cognitive abilities affect how successfully children engage with tablet computes in a learning context, scores on the memory and attention tasks were used to identify homogenous groups of participants who shared similar cognitive profiles. To this end, a K-means cluster analysis (a hierarchical clustering algorithm based on Euclidian distances) was performed on participants' performance on the forward digit span, reverse digit span, spatial span, and controlled attention tasks. The cluster solution grouped participants into two relatively homogeneous groups of cases (see Table 2), with significant differences between the two groups on the digit backward and controlled attention tasks (i.e., executive functioning tasks). Thus, the analysis identified a group of children who possess lower executive functioning ability (i.e., Low EF) and a group of children who possess higher executive functioning ability (i.e., High EF), relative to each other.

Table 2. Performance on the memory and attention tasks by cluster

Task	Score *M* (*SD*)	
Digit Forward (items)		
Low EF	5.17 (1.03)	$t(23) = -0.151, p = .88$
High EF	5.23 (1.09)	
Spatial Span (items)		
Low EF	3.83 (.38)	$t(23) = -0.05, p = .96$
High EF	3.85 (.80)	
Digit Backward (items)		
Low EF	2.58 (.51)	$t(23) = -3.592, p = .002^{*}$
High EF	3.54 (.78)	
Controlled Attention (seconds)		
Low EF	8.76 (5.97)	$t(23) = 3.702, p = .007^{*}$
High EF	3.77 (.82)	

Note. *Scores on the memory tasks represent the total number of items recalled. Scores on the attention task represents the difference in completion time between the same world and opposite world tasks, with lower scores indicating better controlled attention.

To determine how successfully children direct their attention towards intrinsic and germane content and away from extraneous content, two 2 (cognitive ability: low EF, high EF) x 3 (content: intrinsic, germane, extraneous) ANOVAs were performed on the fixation count and fixation duration data. There was a main effect of content type with more fixations in the intrinsic and germane content than in the extraneous content, $F(2, 46) = 19.224$, $MSE = 2267.251$, $p < .001$. There was no main effect or interaction with cognitive ability, Fs < 1.0. The main effect suggests that the intrinsic and germane content is more noticeable/important to the children than the extraneous content whereas an inspection of the graphed data suggests that the high EF children find the intrinsic content more important than the germane content, the same is not true for the low EF children (see Figure 5).

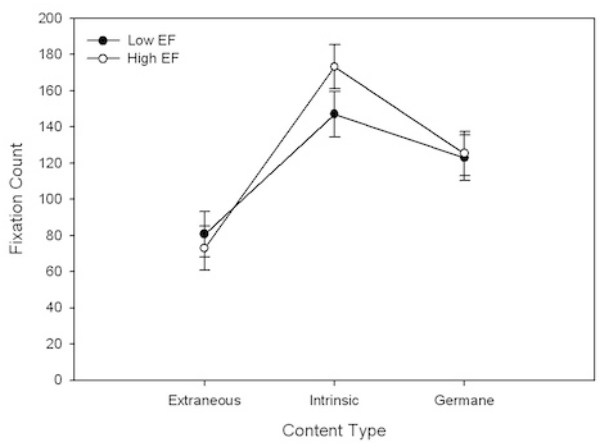


Figure 5. Fixation count by cognitive ability and content (error bars = *se*)

For fixation duration, contrasts revealed that there was a non-significant Content X Cognitive Ability interaction, $F(1, 23) = 3.615$, $MSE = .011$, $p = .07$. The graphed data suggests that low EF children are having more difficulty extracting information than the high EF children, low EF children exert more effort to extract information from the extraneous content, and high EF children exert less effort to extract information from the extraneous content (see Figure 6).

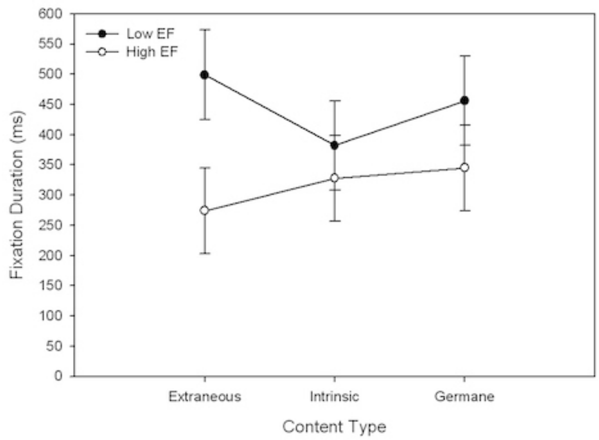


Figure 6. Fixation duration by cognitive ability and content (error bars = *se*)

RQ3. Do application complexity and children's cognitive ability interact?

To determine whether the interaction between application complexity and cognitive ability differentially effect whether attention is directed towards intrinsic and germane content and away from extraneous content, two 3 (content: intrinsic, germane, extraneous) x 2 (complexity: simple, complex) x 2 (cognitive ability: low EF, high EF) ANOVAs were performed on the fixation count and fixation duration data. For fixation count, the Content X Complexity X Cognitive Ability interaction was significant, $F(2, 46) = 5.593$, $MSE = 927.832$, $p = .007$. The graph data suggests that low EF children rely more on the germane content for aid in the simple applications but rely less on the germane content in the complex applications (see Figure 7). In contrast, the high EF children do the opposite—they rely more on the germane content for aid in the complex applications and rely less on the germane content for aid in the simple applications (see Figure 7). For the fixation duration data, the three-way interaction did not approach significance, $F < 1.0$.

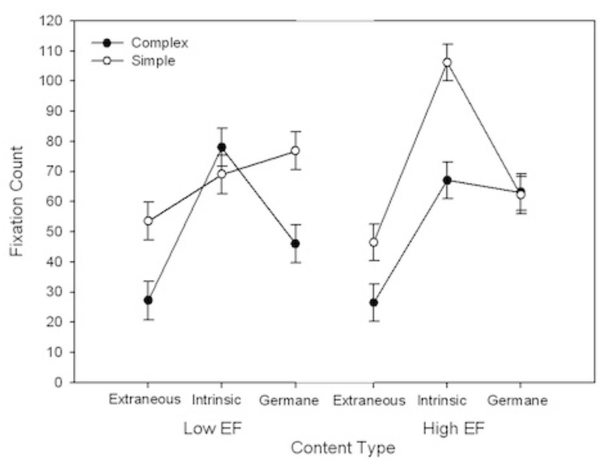
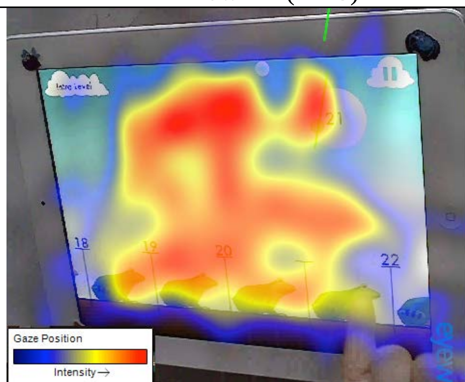
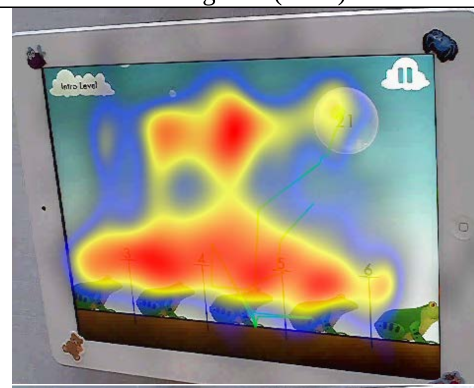
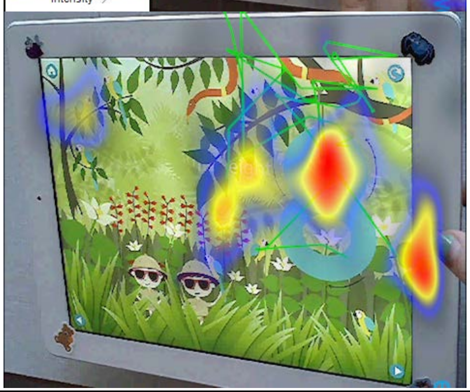


Figure 7. Fixation count by complexity, cognitive ability, and content (error bars = *se*)

To further assess the three-way interaction using the eye tracking data and to present a more concrete representation of the eye tracking data, heat maps of gaze data were generated depicting the sum of all fixation durations within an area. This data was generated from a subset of participants ($n = 9$) because the calibration procedure often required the tablet computer to be moved and this prevents the amalgamation of gaze data due to the tablet computer being physically located in different areas of the eye tracker's scene camera. The physical location of the tablet computer does not affect the other reported analyses, in which the AOIs are individually created for each participant and then used to amalgamate the data. This data can be used to visually compare how attention is divided, with a stronger gaze (indicated in a heat map as red) suggesting that more attention is directed to one area over another (Mello-Thoms et al., 2002; see Table 3). The gaze data heat maps suggest that low EF children's attention is more divided for simple applications and more focused for complex applications. In contrast, high EF children's attention is more focused for simple applications and more divided for complex application. This data supports the previous three-way interaction in the fixation count data in that high EF children take advantage of the germane content in complex applications whereas low EF children seem to take advantage of the germane content for simple applications.

Table 3. Heat maps of gaze data for low and high EF clusters by application complexity

	Cognitive ability	
Complexity	Low EF (*n* = 5)	High EF (*n* = 4)
Simple		
Complex		

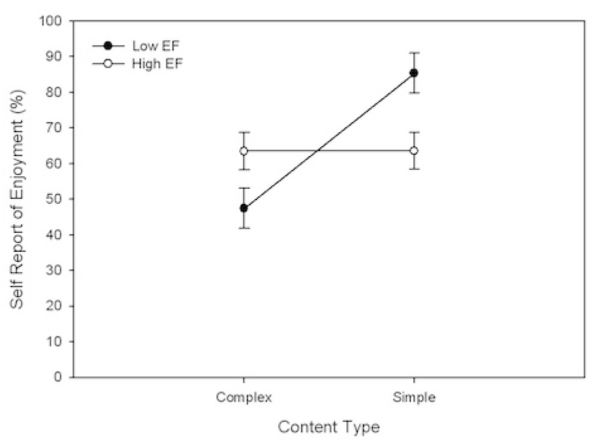


Figure 8. Enjoyment by cognitive ability and content (error bars = *se*)

The previous analyses of the eye tracking data inform how application complexity and cognitive ability affect how children engaged with the educational content on a tablet computer but do not necessarily provide information on how the engagement is experienced by children. To this end, a 2 (complexity: simple, complex) x 2 (cognitive ability: low EF, high EF) ANOVA was performed on children's self-report of engagement. A significant Complexity X Cognitive Ability interaction indicates that low EF children enjoy the simple applications more than the complex applications whereas high EF children have no preference, $F(1, 22) = 5.994$, $MSE = 717.133$, $p = .023$ (see Figure 8). This suggests that low EF children enjoy applications that are in line their cognitive ability.

Discussion

The tablet computer applications were able to direct children's attention to the intrinsic and germane content. From a Luhmann-communications perspective, the design of the content in the applications promoted a successful user-tablet computer communicative encounter because the more educationally cogent information was more visually attractive leading to more successful child-tablet computer interaction, regardless of the children's cognitive abilities.

From a cognitive psychology perspective an interpretation of this result is that the tablet applications all generate high information interactivity – that is, information content cannot be learned in isolation but must be understood by their relations to each other on screen (Sweller, 1994 p. 304-306). For Sweller (1994) in learning scenarios where there is high interactivity—as is this case in the multimedia content found on tablet computers—extraneous cognitive load can interfere with learning. The finding that the extraneous content was less "noticeable" by children may indicate that children were only manipulating and developing schemas for the intrinsic and germane content and did not have working memory available to process extraneous content. Thus, it is both a function of intentionally sound application design and an indication of high interactivity in the educational application learning context.

Another result of interest is that the children assessed as high EF found the intrinsic content from the educational applications more important than the germane content, while low EF children found the germane content more important than the intrinsic content. This could indicate that high EF children were utilizing pre-existing schemas in the processing of intrinsic content (hence a lower germane load), while low EF children needed to create and/or automate schemas to process the intrinsic content encountered in the applications (hence a higher germane load) (Paas et al., 2004).

Two results that appear to be consistent with existing theory from both communications studies and cognitive psychology are that, (a) low EF children appeared to experience more difficulty extracting information from the applications than high EF children; and (b) low EF children seem to take advantage of the germane content for simple applications but high EF children take advantage of the germane content for complex applications. In both (a) and (b) the analysis could be the same, and both communication theorists and cognitive psychologists could agree that children's success in managing and extracting information content is positively related to their cognitive abilities. From a communications theory perspective, more successful user-device communication (messages from the sender is received and understood by the receiver) is indicative of higher cognitive ability. From a cognitive psychology perspective, increased executive functioning is co-related with the child's utilization of existing schemas (i.e., attending to intrinsic content) or the creation and utilization of new schemas (i.e., attending to germane content), when required by a high level of information interactivity (i.e., complex applications).

Conclusion

The primary goal of this study was to explore the relationship between a user's engagement with tablet computers and user's cognitive load, using theories and methodologies from communications studies and cognitive psychology. This goal was attained and the study demonstrates the value of employing an interdisciplinary approach to the study of new media.

There is evidence of the validity of Botha's (1992) claim that the cognitive structure of the individual is intimately linked to the forms or systems of communication used. The research showed that tablet computers and their applications offer a learning experience that appears to be inherently highly interactive and thereby introducing challenges to the cognitive load of children as users. More research is needed to determine whether this finding is generalizable to adults, and a broader range of applications and tablet computers could be investigated to see whether or not subject matter affects the interactivity of information elements in the applications. However, this offers a start in the development of a broader theory on cognitive load and touch devices. An extension of Botha's claim arising from this study is that cognitive abilities/structures may be linked to the forms of communications used, but so is the reverse: the forms of communications are also defined and linked to our cognitive abilities to interact effectively. This offers an example of the co-constitutive nature of media and use.

The use of an eye tracker in data collection was instrumental to the success of this study—many of the results would not have been derived without its use. We hope to encourage other researchers to include this method as part of the data particularly as it allowed for the assessment of vision.

Designers of educational applications should consider these findings in the development of new applications for children. In particular, they could take into account the deleterious cognitive effect of the complex applications on children with lower EF, applications that are typically marketed as being able to engage children who have difficulty learning in "traditional" scenarios. This means that designers could conduct better app testing and invite test participants not just based on age or grade levels, but also include participants with a range of executive functioning skills to offer a better outcome for all users.

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